THE

JOURNAL OF GEOLOGY

A Semi-Quarterly Magazine of Geology and Related Sciences

VOLUME IV

CHICAGO
The University of Chicago Press
1896

PRINTED AT
The University of Chicago Press

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THE

JOURNAL OF GEOLOGY

JANUARY-FEBRUARY, 1896.

REVIEW OF THE GEOLOGICAL LITERATURE OF THE SOUTH AFRICAN REPUBLIC.[1]

Topography.—The most characteristic features of South African topography appear to be its table lands. The interior of the country is in great measure a vast extent of high plateaux —the Hooge Veldt—which, though grassy, are practically treeless and present much the same aridity and desolateness of aspect as many of our western mesas. Along the coast, especially on the south and east, is a belt of country of a generally lower level, which is more rugged and broken, but even here plateaux occur, sometimes on the very coast, as, for instance, the well-known Table Mountain near Capetown.

As one leaves the coast to go into the interior the country becomes more mountainous, often rising into considerable ranges like the Drakensberg range, which runs parallel to the southeast coast and has peaks rising to elevations of 10,000 feet or more.[2]

[1] Read before the Geological Society of Washington, November 13, 1895.

[2] AUTHORITIES CONSULTED IN THE PREPARATION OF THE PRESENT PAPER.

1888. A. H. GREEN: Geology and Physical Geography of the Cape Colony, Quar. Jour., Vol. 44, pp. 239–270.

1889. A. SCHENCK: Vorkommen des Goldes in Transvaal. Zeitsch. d. Deut. Geol. Gesellsch, Band XLI., pp. 573–581.

1890. W. H. FURLONGE: Geology of the De Kaap Gold Fields. Trans. Amer. Inst. Mg. Engrs, Vol. XVIII., pp. 334–348.

1891. W. H. PENNING: A Contribution to the Geology of the Southern Transvaal. Quar. Jour., Vol. XLVII., pp. 451–463.

As a rule, however, these mountains do not reach above the level of the high plateau, which forms an abrupt escarpment near or behind them, and slopes away gently toward the interior. Thus the drainage of the plateau region from within 100 miles or less of the east coast flows westward through the various tributaries of the Orange River into the Atlantic Ocean. The country is yet too new and too little explored by geologists to afford certain data for a physical description founded on its previous geological history, such as would be given by a physical geographer of the present school like our William M. Davis, but it is evident that the region presents a most interesting and fruitful field for this line of study. From what has already been written it is easy to make the preliminary deduction that the coast belt, like the east coast of Lower California, shows an older topography that has been exposed by the denudation of the more recent formations that constitute the plateau regions.

Development.—The general advance of exploration, colonization and civilization has moved eastward and northward, instead of westward as with us. From the older settlements of the Cape

1891. L. De Launay: Les mines d'or du Transvaal. Ann. des Mines, Serie 8 Tome XIX., p. 102.

1892. Walcot Gibson: Geology of Gold-bearing and Associated Rocks of the Southern Transvaal. Quar. Jour., XLVIII., pp. 404–437.

1894. G. A. F. Molengraaf: Geologie der Umgegend der Gold-felder in Süd-Afrika. Neues Jahrb. f. Miner, etc., Beilage Bd. IX., p. 175.

1894. Bergrath Schmeisser: Ueber Vorkommen und Gewinnung der nutzbaren Mineralien in den Süd-Afrikanischen Republik. D. Reimer, Berlin, 1894.

1894. A. Pelikan: Goldführendes Conglomerat von Witwatersrand. K. K. Reichsanstalt, No. 16, December 18, 1894, p. 421.

1895. F. H. Hatch and J. A. Chalmers: Gold Mines of the Rand. Macmillan & Co., New York and London, 1895.

Among geologists who have written in earlier times upon the geology of the southern portion of Africa, but not directly upon the South African republic, may be mentioned A. G. Bain (Quar. Jour., 1845), R. N. Rubidge (Quar. Jour., 1854–6), Andrew Wyley (1857–8), G. W. Stow and C. L. Griesbach (Quar. Jour., 1870), E. J. Dunn, On Diamonds (Quar. Jour., 1874, 1877 and 1881), W. H. Penning, On Coal (Quar. Jour., 1884), Moulle (Ann. des Mines, 1885), E. Cohen (Neu. Jahrb., 1887).

The only geological map of South Africa is one made by E. J. Dunn, as Geologist of the Government of Cape Colony, and published in 1887. This covers most of the South African republic, but has no topographic base, and its geological outlines in the more northern portions are very sketchy.

Colony it spread eastward, then northward along the coast line, and later the search for useful minerals led people into the desolate interior. Coal was the first desideratum, and that was found in the beds of the first high plateau, or Karoo region. Further

NOTE.—The accompanying sketch map shows roughly the political divisions of the southern portion of the African Continent, the location of the principal mining towns and ports, and the main railroad lines.

advances into this region led to the discovery of the diamond deposits, and the foundation of the Orange Free State.

Following northwestward along the coast of the Indian Ocean, through Natal and Zululand, exploration next developed gold-bearing quartz veins in the valleys of the Crocodile River which debouches into Delagoa Bay, and of the Oliphant's and other tributaries of the Limpopo River which forms the semi-circular

northern boundary of the South African republic. This state is more commonly known as the Transvaal, because it lies beyond the Vaal River, the northern and main fork of the Orange River, which divides the South African republic from the Orange Free State.

These first discovered gold fields now comprise many districts, the most prominent of which are the Lydenburg on the north, and the De Kaap and Komati on the south of the Crocodile River. Furlonge describes this region in the following words: "A large plateau stretches from east to west across the Transvaal, which is called the 'High Veldt.' It is generally level or gently rolling, and has an average elevation of 6000 feet above the sea; it is destitute of timber, and in fact greatly resembles the western prairies of North America, and rock outcrops are not common. It terminates very abruptly to the east and northeast, the descent of 2000 to 3000 feet into the mountainous country that occupies its borders being made in a very short distance. These mountains extend in an easterly direction for a distance of forty miles, when they again terminate, very abruptly, in an apparently flat region composed of marshes and sandy plains, sloping gently but regularly to the shores of the Indian Ocean, a distance of about 100 miles."

It was the gold fever, resulting from the rich discoveries in the De Kaap district that started prospecting in the spring of 1886, and caused the unexpected discovery of gold in fair quantity and of great extent in the Witwatersrand (white water range) at the northern end of the great plateau of the Orange Free State and thirty miles south of Pretoria. Toward the end of the same year the township of Johannesburg, now a city of 30,000 inhabitants, was laid out and lots sold to the amount of £13,000. Shares were quoted on the Johannesburg exchange in June 1887, and by November of the same year sixty-eight companies, with a nominal capital of £3,000,000 had been formed. A boom soon set in, which lasted till the end of 1889, when it burst, and the reaction continued for several years, but the increasing output of gold and augmentation of dividends in 1892

and 1893 called the attention of outside capital to the mines again. In 1894 the Transvaal furnished one-fifth of the total gold product of the world, and was only exceeded among individual nations by the United States and Australia.

GEOLOGY.

The geological formations of South Africa are grouped by most geologists under the following four heads given in descending order: (1) recent deposits, (2) Karoo formation, (3) Cape formation, (4) Primary formation.

Recent deposits.—There is apparently no evidence of recent glacial action in South Africa. Dunn, in his early descriptions of the diamond deposits, attributed a glacial origin to certain bowlders observed near the Kimberley district, but afterwards withdrew this explanation of their origin as untenable. Furlonge says of the De Kaap region: "I have diligently searched for, but failed to find, evidences of glacial action, phenomena with which I happen to be very familiar from my residence in the Lake Superior district and the country north of it." Other geologists do not refer directly to the question, but all note the great extent of what they call laterite,[1] a formation which appears to result from the surface decomposition of rock-in-place, and to be similar to that found in the Appalachian region of the United States south of the limits of glaciation. This surface disintegration is so deep and so widespread that outcrops are few and prospecting is thereby rendered difficult. While placer gravels are infrequent and of limited extent, according to Schenck, gold is obtained by hydraulic washing of the laterite (or saprolite) of diabase beds and of surface flows covering the Cape formation in the Lydenburg district, north of the Crocodile River. Furlonge, in his description of the De Kaap region, remarks on the large areas of decomposed granite in flat places and natural

[1] G. F. Becker proposes the term saprolite (from σαπρός = rotten) for decomposed rock in place, objecting to the use of *laterite*, because in its original sense it had a lithological signification, and applies in part to transported material. Gold-fields of the Appalachians, p. 43. Sixteenth Ann. Report Director U. S. Geol. Survey, Wash., 1895.

drainage channels, whose decay he ascribes to the agency of meteoric waters remaining long in contact with the rock. The area on which the town of Barberton is situated is sixteen by eighteen miles in extent. Throughout these areas are what are called "Tongas," that is water-washes, with intricate drainage channels and perpendicular walls, not unlike the Bad-land topography of the West. The depth of this decomposition may reach 200 feet, while on the steep slopes of adjoining hills, and in bowlders rolled down onto the surface, the granite is hard and undecomposed. The same decay is found in other feldspathic rocks.

Primary formation.—Under this head are included granites, and a series of schists called by Schenck the Swasi-schists, because of their abundance in Swasiland to the south and east of the De Kaap basin.

The granite is described by Molengraaf as consisting of microcline granite and of tonalite (plagioclase granite), muscovite being developed in the former as an alteration product of feldspar. Furlonge remarks on its light color and the absence of dark minerals in the De Kaap district. I find no explicit statement of the relative age of granite and schists, but Molengraaf says the schists rest upon the granite, and Schmeisser describes them as dipping away from it in three directions. For the most part these schists appear to be compressed into close folds and stand at steep angles, but in some cases they occupy a nearly horizontal position. While classed under a single head, it does not appear impossible that they may belong to two distinct series of rocks. According to Molengraaf they consist mostly of quartz-sericite and actinolite schists, and in places of conglomerates and sandstones, also carrying sericite. Schmeisser describes them as in part metamorphosed beds of sedimentary origin, such as slates, quartzites and magnetite-quartz (calico) rock, but to a much greater extent of metamorphosed schists with greenstone dikes and sheets, the latter altered into hornblendic, chloritic and serpentinous schists. Molengraaf speaks of quartz-porphyry dikes in the schists around the granite. Schmeisser says gold-bearing veins occur wherever the Swasi formation is developed. They

occur also to a considerable extent in the granite. Schenck considers that the quartz veins are intimately connected in most cases with interbedded sheets of greenstone, sometimes altered into schists, and that the greenstone "appears to be the mother-rock proper of the gold." They appear to resemble the gold veins of the Appalachians in that they are mostly parallel in dip and strike with the stratification (foliation?) planes, or cross them at a slight angle, and are nevertheless true fractures and often contain fragments of the country rock. Furlonge speaks of quartzite-like bands, which, resisting erosion, stand out on the surface in ridges and are called "bars." He considers them to be the result of silicic replacement, and says the principal gold deposits are found in or near these bars, but always in the proximity of some eruptive rock. Often instead of gold they carry deposits of iron oxide of great extent. The gangue of the veins is quartz, and, besides gold, much iron pyrites, some sulphides of copper, antimony, arsenic, lead and zinc occur.

The rocks of this formation stretch northward over 80 kilometers from the steep descent of the Drakensberg, along the eastern border of the high plateau, forming the Murchison range, and constitute the country rock of the De Kaap, Komati, Selati, Little Letaba and Smitsdorp districts. They also occur between Pretoria and Johannesburg. They are considered to be of Silurian age, partly from indistinct fossils remains, but more from stratigraphic correlation with beds underlying uncomformably the Cape sandstones in the Cape Colony, which have been determined to correspond most nearly to the European Silurian.

The Cape formation, so-called because supposed to correspond in age with the Cape sandstones of the Cape Colony, overlies uncomformably the Swasi-schists, and is in turn unconformably overlaid by the beds of the Karoo formation. It contains the gold-bearing conglomerates. Its beds are sometimes upturned, even quite steeply, but are not contorted, compressed or dynamo-metamorphosed to such an extent as are the Swasi-schists. No fossils have yet been found in its beds, but from its relative position, it is supposed to be either Devonian or Lower Carboniferous.

As the most important formation, its description will be given last.

Karoo formation.—Under this head are included a great series of beds, generally occupying a nearly horizontal position, which form the great central plateau or High Veldt of the Orange Free State, and extend into Natal on the east and Cape Colony on the south, leaving a comparatively narrow belt of upturned older rocks between their bluffs and the ocean. Its several subdivisions are variously named and classified in different places and by different writers. Those most commonly adopted are in descending order:

Stormberg beds,	Volcanic.
	Cave sandstones.
	Red beds.
	Molteno beds.
Beaufort beds,	Karoo beds.
	Kimberly beds.
Ecca beds,	Ecca beds.
	Dwyka conglomerate.

The beds of the Karoo formation consist mainly of argillaceous, siliceous, and marly slates and sandstones, with a few limestones; they are generally much softer than corresponding rocks of the Cape formation, and often of variegated colors; the coal-bearing rocks are generally coarse-grained, light-colored sandstones. The two lower of the above general divisions contain a Glossopteris flora (of the fern family) and are hence supposed to be as old as Triassic, and possibly Permian or upper Carboniferous in part. According to Hatch the coal seams are confined to the Molteno beds of the upper division, but Schmeisser, from the finding of Glossopteris remains, considers that some of the coal beds belong to the earlier rocks. The formation is traversed by dikes and sheets of greenstone and other eruptive rocks, especially the middle division.

It is in volcanic necks cutting the Kimberley shales that the diamonds occur, and, as early as 1881, Dunn suggested that they

were formed from the carbon in the shale through the agency of the intruded eruptive rocks.

Near the Witwatersrand the coal-bearing beds transgress horizontally over the upturned edges of the auriferous conglomerates, and coal mines are worked at Bocksburg, Brakspan, Olifants River and other points within 12 to 20 miles of Johannesburg. The coals are gas, coking, blacksmith and steam coals, all varieties being sometimes found in a single district. Beds up to 20 feet in thickness occur. Dunn speaks of an anthracite vein intersecting the Karoo beds vertically at Buffel's Kloof in Cambedoo. Semi-anthracites are found, according to Schmeisser, in Bocksburg and Brakspan, which have a high percentage of ash. The ash from that of the former place, tested by Professor Stelzner, yielded to the assay $4.50 per ton in gold.

Remains of Labyrinthodonts (amphibia), and Dicynodont (few-toothed) and Oudenodont (toothless) reptiles from these beds have been described by Owen and Huxley. Both Equisetæ and Glossopteris occur in the lower Karoo beds, according to Dunn. This peculiar fauna, and more particularly the Glossopteris flora, which apparently was only developed in the southern hemisphere, has called the attention of palæontologists especially to these beds. Schenck says that the fossil flora of South Africa, especially the characteristic *Thinnfeldia odontopteroides*, stands in connection with that of the Argentine republic in South America, with the Radschmahal beds of India, the Hawkesbury and others of Australia, and those in the Jerusalem basin of Tasmania.

In most of these regions the base of the coal-bearing beds, in which this peculiar flora has so suddenly replaced that which in other countries characterizes the Carboniferous formation, consists of a conglomerate carrying peculiarly large, angular rock fragments. These features have seemed to many geologists to indicate the former presence of a southern ice-sheet. On Dunn's geological map the Dwyka conglomerate, which constitutes the lowest member of the Karoo formation, is called "glacial conglomerate." Some earlier geologists, seeing it probably at different exposures, have called it claystone porphyry, others trap-conglomerate.

A. H. Green, who visited South Africa in 1882 for the purpose of examining the coal-bearing formations, speaks of it as a great mass of breccia and conglomerate, in which the fragments are largely granite with some quartzite of varying character and very coarse-grained in places. He considers the volcanic origin that had been suggested for it by no means certain, and remarks that the size and regularity of the pebbles suggest the action of ice and that some of the pebbles observed by him had scratches resembling glacial scratches. On weighing the evidence, however, he concludes that it was a coarse shingle formed along a receding shore line.

He considers that there is a great unconformity between the Ecca beds and the overlying Kimberley shales, which he observed at one point overlapping the upturned edges of the former; he thought to recognize a basement conglomerate at the bottom of the Kimberley shales, which might have been confounded with the Dwyka conglomerate. He is inclined to regard the Karoo formation above the Ecca beds as of fresh water origin. Others have regarded the fossil evidence as in favor of a lacustrine origin for the whole series.

Cape formation.—The beds included under this head are intermediate in lithological character and in degree of deformation, as well as in stratigraphical position, between the Swasi-schists and the Karoo formation. They consist of sandstones, conglomerates and shales, and in some regions of dolomitic limestones. As yet they have proved entirely barren of fossils. They extend over the southern, middle and western parts of the Transvaal. According to Hatch the long range of the Drakensberg consists of these beds, and thus they probably extend to the Cape Colony where they are represented by the Table mountain sandstones and the shales, sandstones and quartzites of the Bokkeveldt beds. The age of the latter by fossil evidence most nearly corresponds to the European Devonian or Lower Carboniferous.

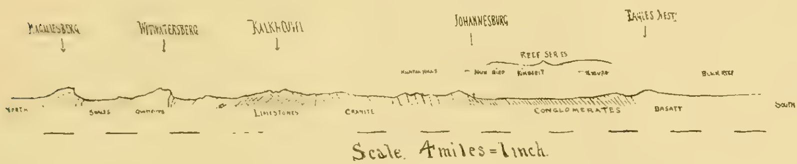
Within this formation name are comprised several series of rocks of very great aggregate thickness, with regard to whose

relations to each other there is some difference of opinion among geologists. They may be separated into three groups.

1. *The Quartzite and Shale group* of Gibson (*Magaliesberg beds* of Penning) underlying the auriferous conglomerates north of Johannesburg, and considered by Gibson to belong to the same series, though separated by a fault, which Molengraaf holds to be an unconformity.

2. The great series of *auriferous conglomerates.*

3. A series of *blue dolomites*, alternating with siliceous or cherty beds. Those which occur in the Malmani district, to the west of Johannesburg, Molengraaf considers to be the upper



Section across Rand.

part of the Cape formation, while immediately north of Johannesburg similar dolomites underlie a series of quartzite and shales, which Schenck considers to correspond to those directly beneath the auriferous conglomerates. These dolomites have a wide distribution in the Western Transvaal and extend into Bechuana land.

The general relations of these beds is shown in a section given by Hatch, which is apparently drawn to scale, and extends from the Magaliesberg on the north, through Johannesburg, to the Black reef beds on the south, a length of over twenty miles. On the line of this section immediately to the north of Johannesburg, are the quartzites and shales, the former standing out as east and west ridges between shale valleys. They have a steep dip to the south, and are succeeded to the north by granite and schists, supposed to correspond to the Swasi-schists. To the north of the granite, and dipping northward away from it, are the dolomitic limestones of the Kalkheuvel range; beyond these again, still dipping north, is a series of quartzites and shales

forming the Witwatersberg and Magaliesberg ranges, which are supposed to correspond with these on the south side of the anticline, though not altogether similar lithologically. If, as Molengraaf maintains, the limestones are the Malmani dolomites, and belong above the conglomerates, the latter must be faulted down on the north side of the granite, and not appear at all at the surface.

Returning again to Johannesburg and following the section line southward, there appear, resting on the quartzites and shales and apparently conformable with them (Gibson thinks they are only separated by a fault, but Molengraaf thinks there is an unconformity) a thick series of reddish sandstones with some shale, which enclose gold-bearing conglomerate beds of varying thickness, and form a flat, rolling country sloping gently south. These dip steeply at the outcrop but shallow in dip to the southward, and in a few miles are capped by a body of eruptive rocks, called by Hatch, in one place, "a hard, fine-grained greenstone or melaphyr" and in another "an overflow of igneous rock of basaltic composition, known as the Klipriversberg amygdaloid." Molengraaf speaks of it as an overflow of diabase and melaphyr amygdaloid with porphyrite, varying in thickness from 400 meters south of Johannesburg to 900 meters near Klerksdorp. This forms the hills called the Eagle's Nest.

Upon the amygdaloid rests a series of shales, quartzitic sandstones, and gold-bearing conglomerates which he calls the Boschrand (wooded mountains), but which are more commonly known as the Black reef series, because of a black seam which forms its footwall. This series Molengraaf considers younger than the lower sediments and than the igneous rocks, but Gibson considers the intrusion of the igneous rocks to have been the latest phase. Hatch, to prove that they were deposited unconformably on the older conglomerates, adduces the facts (1) that they are nearly flat (10° against 45° to 80° dip of the lower beds), (2) that followed eastward they overlap the older series, (3) that they occasionally contain rolled fragments of the older conglomerates. The total thickness of this southerly dipping

series of sandstones and conglomerates, neglecting possible reduplication by faulting, is given as 17,000 to 18,000 feet. Schmeisser enumerates in this series some seventy beds of conglomerates, of which by no means all contain gold, and of those that do, comparatively few have enough to pay for working, or are *payable*, as the South African phrase is. They are generally divided into groups or series of reefs, of which Hatch gives four in descending order beneath the Black reef series, viz., the Elsburg series : the Kimberley series : the Livingstone and Bird series : the Main reef series. The latter is that upon which the principal mines are working today. Beneath the Main reef series is the Dupreez or Rietfontein series, two and one-half miles north of Johannesburg, which has only been traced 10,000 feet along its strike, whereas the Main reef series has been traced more or less continuously for forty-five miles on the strike. Across the strike from the Dupreez outcrops to those of the Black reef series, is eight to ten miles.

As shown by the underground workings these gold-bearing beds are traversed by dikes and sheets of greenstone and considerably faulted.

Twenty-five miles south of Johannesburg, in the Heidelberg region, they are working on a series of a similar conglomerates, which dip 30° to the northward, and are assumed to belong to the south side of a syncline. It has not been possible, however, to correlate the Heidelberg and neighboring Nigel series with those outcropping in the Johannesburg region. Going eastward, on the strike both these and the southerly dipping beds pass within a few miles under the horizontal coal beds of the Karoo formation. The Johannesburg series have been proved under these beds by borings, and are assumed to curve round to the southwestward and find their continuation in the Nigel and Heidelberg fields. To the westward again the Johannesburg beds, at a distance of fifteen to twenty miles from the city, bend to the southwest, toward Potchefstrom and Klerksdorp where similar conglomerates outcrop. The outcrops thus form a sort of horseshoe curve. It is naturally a matter of great importance

to determine accurately the structure of the middle of this basin, where the surface is marshy or shows only outcrops of igneous rocks, and upon this subject much has been written.

Near Johannesburg the dip of the beds is generally 45° to 80° at the outcrop; though in a few instances not over 25°. This inclination decreases with depth, quite rapidly though with no uniformity, and at vertical depths of 500 to 1000 feet, it has usually become 30° or less; the borings show a probable angle as low as 12° at greater depths. Should this decrease continue with sufficient rapidity, the whole basin, even at its deepest part, might be within the limits of profitable mining. Gibson, who is inclined to extreme views in regard to structure indications, says that the surface of the foot and hanging walls of the "reefs" or "bankets" are smooth and polished; the pebbles flattened, and sometimes completely shattered; the cementing material decidedly schist-like and squeezed in and out around the pebbles. He remarks further that the conglomerate beds are generally found to decrease in number as greater depth is reached. All these facts he regards as evidence of strong compressive movement combind with overthrust faulting. The apparent rapid decrease of angle of dip in depth he seems to think due to repetition by reversed faulting and he hence opposes the theory of a simple basin structure. The igneous rocks he regards as much later than the conglomerates, and probably later than the movement of compression, since the diorite intrusions show no effects of it.

Molengraaf, on the other hand, does not consider that there is any considerable folding in these beds, and thinks Gibson's proof of overthrust faulting weak. He admits that both strike and dip faults are common, and that there are evidences of movements within the beds; he considers that these result from thrust faults with movement from north to south instead of from south to north as Gibson maintains. The rapid shallowing of the dip he thinks easily explained if the steep upturning of the beds around the rim of the basin is considered due to dragging of the strata over each other.

The facts presented by Hatch, who devotes much less consideration to geological than to economic questions, lead one to conclude that there is one large and several smaller synclinal basins, none of which can be fully traced on the surface, and which are undoubtedly much broken by dynamic movements which have been accompanied by the intrusion of igneous rocks, mostly on the fault planes, but to a certain extent as intrusive sheets and laccolites. It seems not unlikely that the apparent basin structure indicated by outcrops, will be found to be much broken in depth by these igneous intrusions.

The auriferous conglomerates of the Rand.—The area within which is the principal development of auriferous conglomerates is estimated at 2000 square miles. Gold deposits occur also in other beds assumed to belong to the Cape formation, notably in the dolomites of the Malmani district, as vertical quartz veins, and in the sandstones of the Lydenburg district, which rest on dolomites. None of these have yet assumed any considerable economic importance, however, and it is the area called for short the "Rand" that produces over nine-tenths of the South African gold.

In this area, though gold is found in most all of the several reef series enumerated above, it is rarely in paying quantities outside of the Main reef series, upon which most of the mines near Johannesburg are working. In this series are several beds of conglomerate known respectively as the north, main, middle, and south reefs, and main and south reef leaders (this name is given to thin beds of conglomerate) not more than two or three of which are usually productive in the same mine. Schmeisser says the tenor in gold varies inversely with the thickness of the beds, and in many mines the principal values are obtained from the main reef leader, which averages only 15 inches in thickness while some of the reefs average six feet. Although there is considerable variation in the richness of the different beds, and of the same beds from one point to another, yet taking the district as a whole the gold seems to be distributed with remarkable uniformity, as compared with other mining districts. Schmeisser

estimates $15.00 per ton as the average tenor of the ore mined throughout the whole district. Hatch puts it at $10.00, or half an ounce.

The central district of the Rand, on the Johannesburg side of the basin where the greatest concentration of mines exists at present, is 11½ miles long. The workings of these mines extend now to a depth of 800–900 feet in the case of those which started from the outcrop, while deep-level mines, or those which do not own the outcrop, are down as far as 2000 feet, in each case reckoned on the dip. Drill holes sunk at various points in this extent, to vertical depths of between 2000 and 3000 feet, have proved the gold bearing conglomerates to distances of up to 8000 feet from the outcrop, and found, for the points thus tested, about the same average tenor in gold as higher up, with similar variations from point to point.

The conglomerate beds and the sandstone which enclose them have a reddish tinge near the surface which is due to the oxidation of the finely divided iron, but in depth have the greenish or bluish-gray color common to rocks containing sulphides of iron. The conglomerate beds vary in thickness from a few inches up to six or more feet, and the pebbles of which they are composed from the size of a pea to that of a hen's egg or even larger. These pebbles are generally smooth and well rounded, sometimes flattened and not infrequently cracked and fissured; angular pebbles are also found. They are mostly composed of white or smoky quartz; quartzite is also mentioned as a constituent. Gibson speaks of pebbles of a yellowish talcose material, like hardened clay, which may be altered igneous rocks. The cement consists mostly of small quartz fragments, and abundant but irregularly distributed pyrite grains. Under the microscope it is seen to contain, beside quartz and gold, pyrite, magnetite, zircon. rutile, muscovite and chlorite, the last two minerals and some of the quartz being of secondary origin. The gold, which occurs almost exclusively in the cement, is generally invisible to the naked eye. When it does occur in the pebbles it is found in the delicate cracks or fissures associated with quartz which appears

to be secondary. Gold is sometimes found also in the sandstones between the reefs.

Numerous dikes and some intrusive sheets traverse the beds; the intrusive rocks are generally basic; diabase, olivine and bronzite-diabase, gabbro and olivine-norite being among the varieties recognized. The dikes generally follow fault planes. The faults, which are quite frequent, are both dip, strike and reversed faults. Quartz veins are said to cross the gold-bearing beds, and at the intersection the quartz becomes quite rich.

Origin of the gold.— From the very earliest discovery of these deposits the question as to how the gold came to be distributed in such quantities over such great areas and in so many different beds has been one that has occupied the attention of all geologists who have visited the region. Probably the largest number, certainly among the earlier observers, have considered that the gold, like the pebbles of which the beds consist, results from the degradation and concentration by sea waves of material from an ancient landmass of Swasi-schists. They have seen in the quartz of the pebbles a resemblance to that of the veins which are so abundant in these rocks in the De Kaap and other outlying districts. A few have held that the gold was chemically deposited from the waters of the ocean; and another, and in late years an increasing, number believe that it has been deposited from ascending or descending thermal solutions.

Schmeisser brought back specimens of the conglomerate ore from six of the principal mines of the Rand, which were submitted to Dr. Koch for microscopical examination. The main results of this examination are as follows:

The pyrite shows the effects of wear in rounded edges, etc., and also occurs within the quartz pebbles; hence it is undoubtedly of primary origin. The same is true of the magnetite and zircon. The rutile is, however, not original, and the muscovite and chlorite are evidently formed from the alteration of other minerals. Secondary quartz occurs both in the matrix and filling the cracks in the pebbles that result from dynamic action; it contains fewer inclusions than the primary quartz. The gold con-

tained in the specimens (eight in number) that he examined is of secondary formation and not placer gold, for the following reasons:

1. It occurs either in microscopic crystals or in aggregates of angular form. Rounded and polished grains are altogether wanting.

2. It is not observed as inclusions in the quartz pebbles, but is confined to shattered zones and fissures filled with secondary quartz.

3. In the matrix, the gold is aggregated with pyrite grains, for the most part forming deposits on the outside of them, filling cracks and bays in them, and sometimes nearly enclosing them. It is noticeable, moreover, that the gold is connected only with grains of pyrite that have been separated from their matrix. The pyrite that is still enclosed in quartz pebbles is free from gold.

In conclusion he says: "Whether the above observations on the occurrence of native gold can be considered of universal application, or whether they only fit local phenomena must remain undecided for the present and can only be finally determined by the investigation of more extensive and complete material than was submitted to me."

Pelikan, on the other hand, from the examination of five specimens from, in part, the same mines, brought back to Vienna by Professor Suess, comes to a different conclusion with regard to the origin of the gold, though confirming the correctness of Koch's observations in every other respect. His reasons are not so clearly or definitely stated as those of Koch, but seem to be mainly the following:

1. The nature of the pebbles indicates that they came from quartz veins; they have the same colors as are described for the vein quartz of the Swasi-schists.

2. The form of the gold—in grains (Körner) and in flakes (Flittern)—as well as its distribution in the rock, indicates its foreign origin.

3. As regards the critical question whether gold occurs in the

pebbles, he says that after searching a great number of thin sections he has found moss-gold in one or two; and moreover that after grinding up the rock and treating it with *aqua regia* to dissolve the free gold, the quartz fragments often showed included gold that had not been removed. He says, moreover, that Schmeisser answers this question in the affirmative.

This is not, however, a fair statement of the latter's opinion, which in his own words is as follows: "The gold occurs almost entirely in the cement or matrix, in rare cases also in the pebbles. In the latter cases, however, it appears to be found only in the minute cracks that traverse the quartz." Koch, from whose observations he formed his opinion, considers, as shown above, the gold in such cracks to be the secondary, as well as the quartz which encloses it. His (Schmeisser's) final words with regard to whether the gold was deposited with the conglomerate as "fossil placer deposits," or was brought in subsequently in solution, are: "The observed phenomena bear evidence in part for the one, in part for the other solution."

Hatch, while declining to discuss the various hypotheses that have been brought forward, says, that the quartz pebbles are derived from veins in the Primary formation, but they are not the source of the gold because it does not occur in them (the pebbles); that the movements produced faulting; that the dikes followed the fault fissures; and that the same planes acted as channels for the introduction of ascending mineralizing solutions. He says that no evidence has been found in favor of the locally prevalent theory that the dikes have acted beneficially, as regards gold contents, on reefs in their immediate neighborhood.

The Future of the Rand.—So much attention has evidently been given to the question of the origin of the gold not only because of its intrinsic interest, but because it has an important bearing upon the future productiveness of the region.

The grounds on which auriferous conglomerates outcrop have, it may be assumed, been all taken up or "pegged out," as the South African phrase is; and already many so-called deep

level mines have been opened; *i. e.*, those whose surface lines do not include the outcrop, but which like the Tamarack and other conglomerate mines at Lake Superior, first reach the payable beds at considerable depths. How far from the outcrop toward the middle of the basin it may be profitable to open deep level mines, depends upon three factors:

1. The angle at which the beds descend, or the depth at which they will be found under a given point on the surface.

2. The vertical depth at which the difficulties of mining will neutralize the profit.

3. The extent in depth, or the distance from the outcrop to which the conglomerate beds will continue to be payable.

If the gold is entirely placer gold, that is if it has all been brought into the beds mechanically, by the action of sea waves —there has been no suggestion of old river channels—it is evident that there must be a limit to the distance from the shore to which so heavy a metal could have been transported.

That wave action may concentrate the gold in beach gravels sufficiently to constitute workable placers, has been proved on the coasts of California, Oregon and Alaska, though practically such placers have not yielded much profit to those working them, because the pay streaks are constantly shifted by storms and ocean currents.

The best authenticated instance of a fossil placer on an old shore line (not a river bed) known to the writer, is the conglomerate at the base of the Potsdam sandstone, near Deadwood in the Black Hills. According to W. B. Devereux,[1] who has given the best description of these deposits, the conglomerate which is rich enough to be profitably mined occupies a narrow belt, not over one and one-half miles wide, in the immediate vicinity of the Great Homeslates group of deposits in the underlying crystalline schists, from the degradation of which it is evidently derived. The gold in the Potsdam quartzite of Bald Mountain and other districts of the Black Hills, however, is found, not in rounded pellets and flattened flakes, but finely divided and, when visible, is in the

[1] Trans. Amer. Inst. Mg. Engrs., Vol. XVII., p. 572.

brown powdery form that comes from precipitation. This he considers to have been chemically deposited as a result or sequence of the intrusion of igneous rocks in sheets or dikes, and more or less contemporaneously with the ores of silver that occur in these rocks.

That gold may be carried to a considerable distance from the shore in the waters of a sea or lake, is proved by deposits recently examined by the writer near Denver, Col., where payable placers occur, at fifteen miles or more from the ancient shore line of the lake, in Tertiary beds made up of detritus of granitic rocks that form the nucleus of the Colorado range. In this case, however, the gravels that contain enough gold to be worked result from the rearrangement and concentration of the Tertiary lake beds in an ancient stream bed, the gold in the undisturbed Tertiary beds being too small in amount to be of economic value.

Explorations within the conglomerate beds of the central district of the Rand have, as already shown, extended about one and one-half miles from the outcrop (which may be somewhere near the ancient shore line) and are still within the payable limit, but this does not prove that at several times that distance the payable limit may not have been passed. The fact, mentioned by Schmeisser, that the beds are generally richest at the bottom where the gravel is coarsest is, in so far, an evidence in favor of the placer theory. On the other hand many facts presented above seem incompatible with this theory, so that it would seem probable that while the beds contain gold that has been introduced mechanically, they also contain some that has been added chemically since the formation of the beds by concentration, either from adjoining sedimentary or from igneous bodies along areas that have been rendered accessible by dynamic movements.

As to the other two factors, it seems abundantly proved that the steep dips at the outcrop do not continue in depth, but at what depth the auriferous conglomerates will be found in the middle of the basin can only be finally determined by actual exploration with the drill.

The practical limits in depth at which mining can be profit-

ably carried on, have been recently extended by the experience of the Lake Superior mines, where the new shaft at the Calumet and Hecla mine is down below 4700 feet and destined to go to 5000. In this case, however, conditions are unusually favorable, for the increment of temperature with depth is, according to a recent statement of A. Agassiz,[1] only 1° in 223 feet, or 79° at the bottom of the present shaft. In South Africa the increment as determined by Hamilton Smith is 1° in every 82 feet, which would produce a temperature of 100° at 3000 feet. This increment, though below the average, is, there is reason to believe, somewhat overestimated; more recent estimates make it less than 1° for every 100 feet, which would give only 108° (F) at 4000 feet.

Production, Past and Future.—In conclusion it may be of interest to consider some of the figures showing the gold production of this remarkable region.

Its output for 1894 was gold to the value of £7,800,000 and for 1895 it is estimated to reach nearly £8,750,000. Hatch estimates that by 1900 the annual output will be over £20,000,000. Up to July 1895 it had already produced £26,670,539. Estimates of the available supply of gold in the central district of the Rand with its eleven and one-half miles of outcrop are given as follows:

By Hamilton Smith - - - - - -	£325,000,000
" Bergrath Schmeisser - - - - -	346,000,000
" F. H. Hatch - - - - - - -	382,000,000

As these estimates have been arrived at independently and by somewhat different methods, Hatch allowing a greater depth for profitable working than the others, their slight difference is rather remarkable. Hatch further estimates a probable product for the whole region, including outlying districts, of £700,000,000, of which £200,000,000 will be profit. This amount is greater than the product of the whole United States up to date.

S. F. Emmons.

[1] Am. Jour. Sci., Vol. L, Dec. 1895, p. 503.

IGNEOUS INTRUSIONS IN THE NEIGHBORHOOD OF THE BLACK HILLS OF DAKOTA.

On the northern border of the Black Hills of Dakota, and situated partly in Wyoming, there are about a dozen hills of igneous rock, which not only add variety and beauty to the picturesque region where they occur, but are unique topographic features and furnish examples of a type of igneous intrusions that does not seem to have been clearly recognized.

The hills referred to, are known in the general order of their occurrence from east to west, as Bear Butte, Custer Peak, Terry Peak, Black Butte, Crow Peak in South Dakota, Inyan Kara, the Sun Dance hills, Warren Peaks, Mato Tepee or Bear Lodge, and the Little Missouri buttes in Wyoming.

Only a few of these hills have been examined by me, but such observations as I was able to make together with the descriptions given by N. H. Winchell[1] and Henry Newton[2] of those not visited, show that they all have a common history and may be classed in a single group.

Each of these hills owes its existence to the injection from beneath of a column of molten rock into stratified beds, and the subsequent removal of the enclosing sedimentary strata so as to expose, with one exception, the inner core of plutonic rock. They differ from the laccolites described by G. K. Gilbert[3], in the fact that the molten rock did not spread out horizontally among the stratified beds so as to form "stone cisterns,"

[1] Geological Report. In report of a reconnoissance of the Black Hills of Dakota made in the summer of 1874, by William Ludlow, Washington (Engineer Department, U. S. A.), 1875, 4to, pp. 21–66.

[2] Geology of the Black Hills (edited by G. K. Gilbert). In report on the geology and resources of the Black Hills of Dakota, by Henry Newton and Walter P. Jenney, Washington (Department of the Interior), 1890, 4to, 1–222.

[3] Report on the Geology of the Henry Mountains; Washington (Department of the Interior), 1877, 4to, pp. x.+160, Plates I.–V.

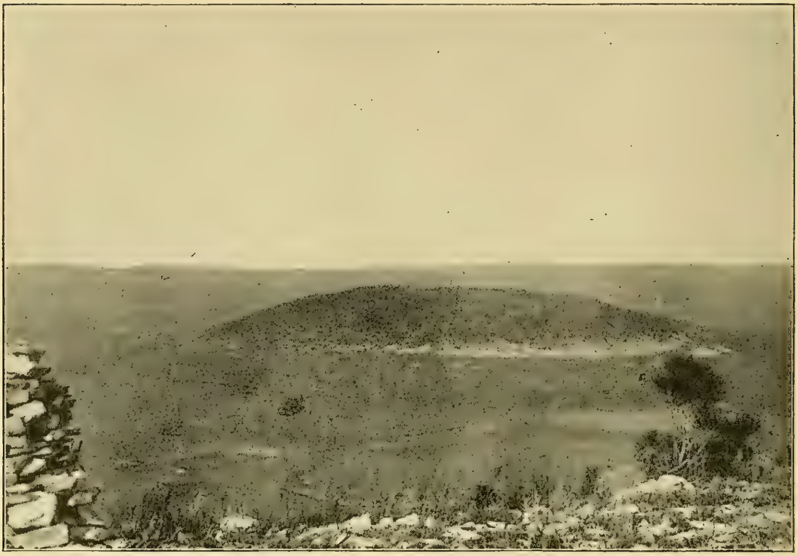


FIG. A.—Little Sun Dance Dome from the summit of Sun Dance Hill.

FIG. B.—Inner escarpment of limestone encircling the summit of Sun Dance Dome.

although some of the hills named, which had not been examined by the writer, may reveal this structure when more thoroughly examined. They differ, also, from volcanic necks like those of New Mexico described by Captain Dutton,[1] to which some of them have a superficial resemblance, in the fact that the injected rock did not reach the surface so as to form either coulees or cinder cones. As they are composed of igneous matter forced into sedimentary strata and have a plug-like form, it will be convenient to call them *plutonic plugs*.

In the hills examined by the writer the structure has been revealed in varying degrees by denudation, so that an examination of a few examples furnishes a series of illustrations ranging from an unbroken dome of stratified rock arching over the summit of a concealed mass of plutonic rock, to imposing towers of columnar rhyolite several hundred feet in height, exposed by the removal of the softer strata into which they were intruded.

The first in this series is Little Sun Dance dome. This is a regular dome of stratified rock, about a mile in diameter, the outer layers of which have been removed and the inner ones of resistant limestone, deeply gashed by erosion, but not dissected sufficiently to expose the top of the igneous plug which presumably exists beneath.

The other extreme is shown by Mato Teepee. In this instance the arch of stratified rock which once surmounted the summit of the plutonic plug has been completely removed and the surrounding strata eroded away.

The rocks of which the plutonic plugs are composed have been studied microscopically by J. H. Caswell[2] and found to be rhyolite and sanadine-trachyte.

The rock composing the several hills is closely similar in general appearance and in chemical composition and crystalline structure. It is described in the report just referred to, as light-

[1] Mount Taylor and the Zuni Plateau. In 6th Annual Report of the U. S. Geological Survey, 1884–5, Plates XI.–XXII.

[2] Microscopical Petrography of the Black Hills of Dakota. In report of the geology and resources of the Black Hills of Dakota, by Henry Newton and Walter P. Jenney, Washington, pp, 489–527, Plates I.–II.

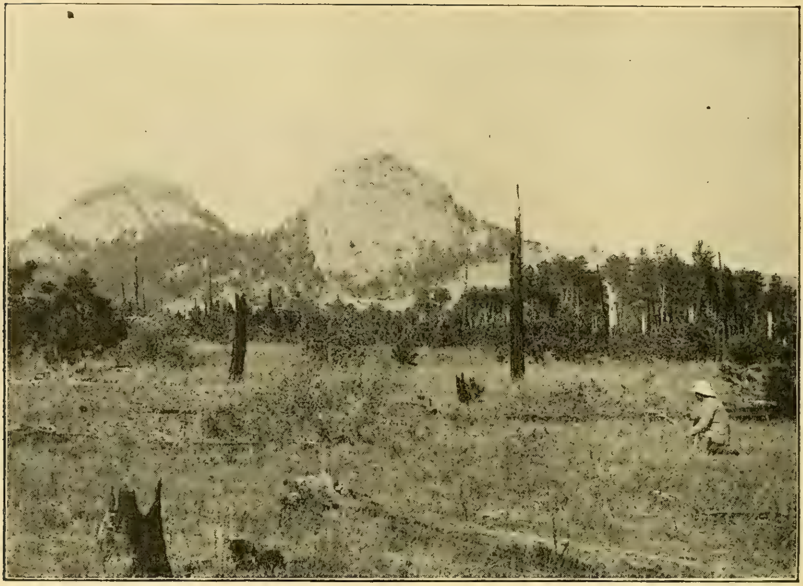


FIG. A.—Sun Dance Hill from the southwest.

FIG. B.—Little Missouri Butte from the east.

colored, compact and usually coarsely crystalline; and contains prominent crystals of sanadine, quartz, biotite and hornblende.

In the hills examined by the writer, namely, the Sun Dance hills, Mato Teepee and the Little Missouri buttes, the rock appeared to be of the same character in each instance. In hand specimens it was impossible to distinguish any essential difference. For a more exact description of the rocks in question the reader is referred to Mr. Caswell's report which contains the results of the only systematic study of them that has been made.

The stratified beds through which the plugs have been forced, vary in age from the Potsdam to the middle of the Cretaceous. In a conglomerate discovered by W. P. Jenney[1] at the base of the Miocene in the neighborhood of the Black Hills, pebbles of igneous rock were found which must have been derived from the hills now claiming our attention. The date at which the plugs were formed is therefore somewhere between the Middle Cretaceous (Fort Pierre group), which was disturbed and altered by their intrusions; and the base of the Miocene, at which date they were exposed to erosion and contributed pebbles to neighboring streams.

In discussing the date of the origin of these rocks, Newton[2] observes that the interval mentioned above, witnessed the deposition of the Niobrara, Fort Pierre, Fox Hill, Judith River and Fort Union terrains, which represent a total depth, in the upper Missouri region, of about 4000 feet of sedimentation. The date of the igneous activity is therefore very far from being definitely established, and its relation to the main Black Hills uplift is not determined. The igneous rocks may have been in place and even ancient when the elevation of the Black Hills began, or they may have been forced up while the greater movement was in progress.

With this introduction, such facts of geographical and geological interest as are available concerning these remarkable intrusions will be presented.

[1] Geology of the Black Hills, p. 220.

[2] *Ibid.*, 220.

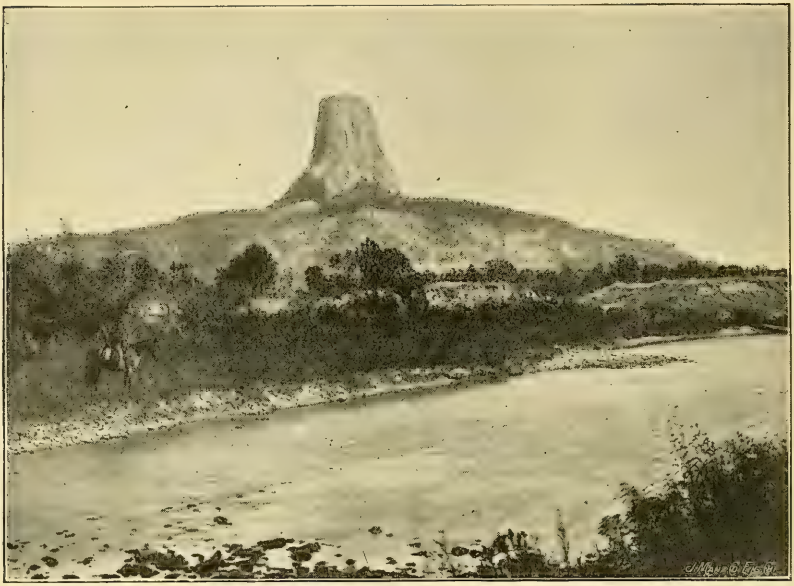


FIG. A.—Mato Teepee from the valley of the Belle Fourche.

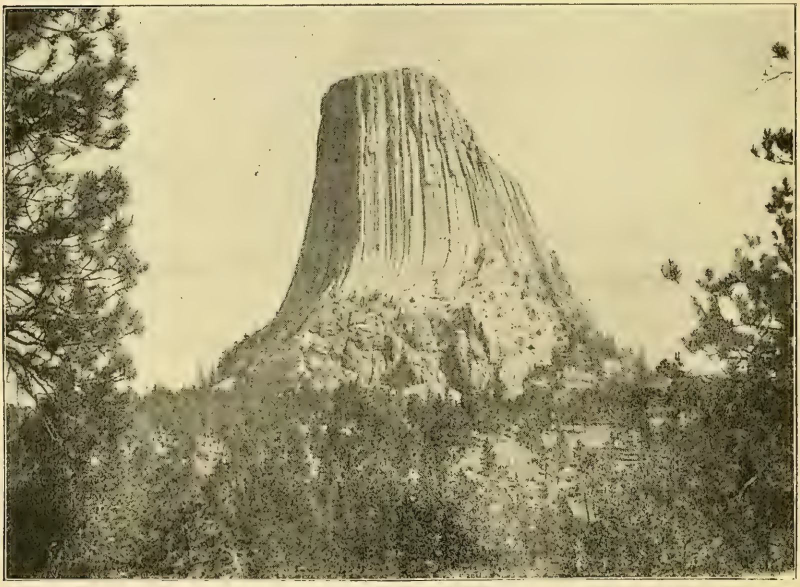


FIG. B.—Mato Teepee from the southwest.

Little Sun Dance dome.—This hill, sometimes called Green Mountain, is situated about two miles northeast of the town of Sun Dance, the county seat of Custer county, Wyoming, and about three miles north of a larger uplift of the same character, known as Sun Dance hill.

A view of Little Sun Dance as seen from the topographic monument on the summit of its more imposing companion, is given in Fig. A, Plate I. This dome is remarkably regular from whatever direction it is seen, and is composed of stratified rocks which have without question been elevated by a force acting from below directly upward. The summit of the hill consists of Carboniferous limestone, the crown being an unbroken dome. About this inner dome and dipping sharply in all directions are strata of purplish limestone belonging to the Red Beds or Triassic system. This resistant layer has a thickness of about twenty feet, and was once continuous over the top of the dome, but has been removed from the summit by erosion, and several radiating gorges cut by streams in the portion of the envelope which remains. Between the drainage lines the strata extend far up on the sides of the dome so that the edge of the outcrop when followed about the hill forms a zigzag line. As described by Newton, the exposed edge of this limestone resembles the broken edge of a piece of paper that has been punctured by a sharp pencil. Although the strata have been bulged upward, they have not been shattered, the apparent radial breaks being due entirely to erosion. Resting on the limestone, are soft, easily eroded shales, a hundred feet or more in thickness. The position of this bed is indicated about the base of the hill by a smooth, grassy valley a few hundred feet in breadth. On the outer side of this valley is a rampart, more or less well defined, of sandstone layers, which dip away from the dome in all directions but present a steep inner escarpment. The sandstone and shale belong, together with the purple limestone, to the Red Bed system, and are the highest or youngest strata exposed in the immediate vicinity.

The streams which have eroded deep trenches in the sides of

the dome, radiate from its center and, with one exception, are active only during wet weather. At the head of a deep, wooded gorge which leads northward from near the center of the uplift, there is a small spring from which flows a perennial rivulet. A view looking down this channel is shown in Fig. B, Plate I. The rock forming the cliffs is purple limestone and shows the character of the zigzag escarpment that Newton compares with the torn edges of the paper through which a pencil has been forced.

An examination of the bottoms of the drainage channels on the summit and sides of the Little Sun Dance dome, and of the débris with which they are partially filled, failed to reveal even a fragment of igneous rock.[1]

The most interesting facts connected with the geology of the Little Sun Dance dome are, that the rocks were elevated by an extremely local force acting from below upward, and that the strata which suffered deformation were not fractured, or sensibly metamorphosed, during the process. The absence of fractures in the crown of the dome, as well as the vast amount of erosion which is known to have taken place in the region in which it is situated, show that the bending of the rocks must have taken place under a great weight of superincumbent strata.

Sun Dance hill.—This hill is not only higher and larger than the one just described, but differs from it widely in its topographic form. As seen from Little Sun Dance, it represents a bold scarp to the west and declines more gently and with many undulations in other directions. The western scarp (Fig. A, Plate II) is composed of plutonic rock and has steep talus slopes at its base. The flanks of the hill, especially on the east, are composed of Red Beds, somewhat upturned. These strata extend entirely about the central core of intruded rock and slope away from it at low angles in all directions.

A geologist on visiting Sun Dance hill, after examining its smaller neighbor, would say at once that the two uplifts are very similar in many ways. In Sun Dance hill the intruded rock was

[1] This hill is marked as igneous on the map accompanying Newton's report on the geology of the Black Hills.

forced to a higher level than the present crown of the Little Sun Dance dome, and has been well exposed by the removal of surrounding strata. As these hills stand near together on the same plain, it is evident that they have been exposed to the same erosive agencies. The larger hill is higher for the reason that the plug forming its center was forced to a higher level in the stratified beds and is also of greater diameter than the similar plug which presumably caused the upheaval of the smaller hill. It is also to be noted that the sedimentary beds surrounding the larger intrusion show less disturbance than those around the smaller uplift, which has been dissected less deeply in reference to the top of the column of igneous rock. This indicates that the greatest amount of disturbance among the stratified beds occurred near the summits of the intruded columns.

Mato Teepee.—This remarkable tower has been described very fully by Newton,[1] and to his account of it we are indebted for the measurements here used. It stands on the west bank of the Belle Fourche River, about twenty-two miles northwest of the Sun Dance hills, and six miles southeast of the Little Missouri buttes, next to be described.

As stated by Newton, the name "Bear Lodge" is used on the earliest maps of the region, although more recently it is said to be known among Indians as "the bad god tower," or in better English, "the Devil's tower." Mato Teepee, meaning Bear lodge, seems to have been the original Indian name and will be used in this paper.

Something of the impressive grandeur of this lonely column may be gathered from the accompanying pictures. Fig. A, Plate III., is reproduced from a photograph taken on the banks of the Belle Fourche about two miles in a direct line south of the tower. Even at this distance the clustering columns that combine to form the structure may be easily distinguished. Another view, showing the columnar structure still more clearly is also given on Plate III., which is from a photograph taken about a quarter of a mile southwest of the tower.

[1] Geology of the Black Hills, pp. 200–202, and frontispiece.

The platform surrounding the base of Mato Teepee as seen in Fig. A, Plate III., is not a remnant of a coulee of lava or the remains of an ancient cinder cone, as might be supposed from a distant view, but is composed of sandstones and shales belonging to the Red Beds and the Jurassic formations. The stratification of these beds, even up to the base of the tower, is horizontal and undisturbed. Some change in texture, however, may be observed in the strata in the immediate vicinity of the intruded rocks, showing that they were hardened and somewhat metamorphosed when the igneous material was forced in among them.

When Mato Teepee is seen from almost any locality in the valley of the Belle Fourche within a radius of several miles, one is not only forcibly impressed by the grandeur of the monumental form that dominates the landscape, but is delighted by the brilliant and varied colors of the rocks forming the sides of the valley and the immediate base of the tower. The Red Beds in the lower portion of the river bluffs show many variations of pink and Indian red, and have been sculptured into architectural forms of great beauty. The less brilliant Jurassic sandstones resting upon them and forming the upper portions of the bluffs, serve to carry the eye from the rich colors below to the dark forest of pines that grow above and to the still more somber precipices of the great tower which always appears in bold relief against the sky.

The platform on which Mato Teepee stands is 500 feet above the river, while the tower proper rises almost vertically 626 feet above it. The tower is nearly rectangular in cross section; the width at the summit from north to south, being 376 feet, and the width at the base 796 feet.[1] The shaft of the column is composed of clustered prisms which extend from base to summit without cross divisions. These prisms are usually pentagonal, although other forms are not uncommon. Most frequently they have a diameter of from eight to ten feet. Each prism tapers somewhat toward the top, and near its upper extremity is cracked

[1] Geology of the Black Hills, p. 201.

and discolored by weathering. At the base of the tower the columns in most instances, except at the southeast corner, curve abruptly outward, and, at the same time, increase somewhat in size. On the west side they become nearly horizontal and are soon lost to sight beneath accumulations of débris. Near the base of the tower, just above the treetops, as seen in Fig. B, Plate III., the rock loses its columnar structure, becomes massive and breaks with an irregular fracture. On the sides of the tower there are a few places where the lower portions of individual prisms have fallen away, leaving the upper two or three hundred feet still in place. In such instances one has a good view of a section of the prisms, which are seen to be four, five or six-sided.

Owing to the abrupt outward curvature of the columns at the west base of the tower, the fragments that have fallen from above have been thrown farthest out on that side and now form an extremely rugged talus in which fragments of huge columns lie piled in endless confusion one on another, suggesting the ruins of some mighty temple.

As shown in the accompanying illustrations, the sides of the tower are nearly perpendicular. This fact is still more impressive in nature, especially when one stands at the base of the great prisms, each of which is an uniform column over 500 feet high, and looks upward. The strongest and most experienced mountain climber must pause when he has scaled the rugged cliffs which form the immediate base of the tower and gains the point where the individual prisms make their abrupt curve and ascend perpendicularly. Beyond that point no man has ever reached, and, it is safe to say, never will, unaided by appliances to assist him in climbing.

To gain a comprehensive view of Mato Teepee and of its relations to neighboring cliffs and plateaus, one should go about two miles west from the tower and ascend to the top of the table-land which has been cut away to form the valley of the Belle Fourche. Standing on the border of this table-land which rises more than 1000 feet above the silvery thread marking the course of the river in the valley below, one is a little lower than the

top of the tower which is the most prominent object in the landscape. On looking west from this point of view, it is at once apparent that the observer is on the immediate border of a tableland which stretches away far beyond the limits of view. On this plateau and four or five miles distant, stands a group of three hills known as the Little Missouri buttes.

It requires but a glance from almost any commanding position in the neighborhood of Mato Teepee, to show that the valley of the Belle Fourche has been eroded in the flanks of a broad uplift, which culminates several miles to the east in a great dome-shaped elevation known as Mount Warren. In fact the rocks removed to form the valley hardly interrupt the gentle sweep of the sky-line as one follows the profile of the land on looking southwest. It is at once apparent to every observant person who looks down on the valley of the Belle Fourche from a commanding station, that the stratified rocks which form the bordering bluffs of the valley were once continuous, and that the whole depression has been formed by erosion. Mato Teepee rises from the bottom of this valley and must at one time have been surrounded by the strata that have been carried away. It is a monument of erosion not unworthy of the great events it commemorates. Restore the rocks which have been removed in order to form the valley up to the level of the cliffs on which the reader is supposed to stand, and Mato Teepee would be nearly buried. A thousand feet of rock have been removed to form the valley about it, but this does not represent the entire amount of the erosion that has taken place. This is shown by the history of the Little Missouri buttes which stand on the plateau stretching west from Mato Teepee. These hills are of the same nature as the great tower in the valley below, and were intruded among sedimentary strata that rested on the platform above which they now rise. As their tops are more than 500 feet above the plateau, it is evident that more than this thickness of rock has been removed in order to expose them.

As erosion goes on, the rocks forming Mato Teepee will crumble and be carried away by the stream which is even now

encroaching upon its base, while the plugs forming the Little Missouri buttes will become more and more prominent as the stratified rocks are removed from about them, and when the valley of the Belle Fourche shall have been broadened so that the waters of the river wash their bases, will form towers of the Mato Teepee type.

The total amount of erosion that has taken place in the region about Mato Teepee cannot be accurately determined from the study of the local topography, but is certainly greater than the vertical distance from the bottom of the valley to the topmost crag of the Little Missouri buttes, that is, over 1500 feet. As shown by Newton, more than 4000 feet of Cretaceous and Tertiary strata have been removed from the Black Hills region.

The Little Missouri Buttes.—These buttes, as already stated, are formed of igneous rocks of the same character as those composing the Sun Dance hills and Mato Teepee. They are three in number and occupy the angles of a triangle, the distance between them being about three-fourths of a mile. Among the Indians they are said to be designated by a term which means "the buttes that look at each other."

The summits of the Little Missouri buttes are of bare rock, sometimes showing a columnar structure, and resemble the summit of Mato Teepee, except that they are less flat. The junction of the igneous rock with the surrounding Cretaceous sandstone is obscure, but the stratified rocks are well exposed near at hand and gives no indication of having been disturbed in bedding or altered in texture. Newton[1] reports that in one or two localities near the base of the buttes a tuff-like rhyolitic breccia was found in which were imbedded fragments of both sandstone and rhyolite.

The view of the buttes here presented, Plate II. (in which only two of them are seen, the third being to the left and beyond the field of view) is from a photograph taken at a locality on the Cretaceous plateau about a mile distant from the nearest hill in the direction of Mato Teepee.

[1] Geology of the Black Hills, p. 203.

The Cretaceous sandstone surrounding the base of these buttes is the youngest of the stratified rocks which come in immediate contact with the igneous intrusions we are studying, and presuming that all the igneous rocks are of the same date, records the upper limit as nearly as can be determined, to be placed on estimates of the time of their origin. That is, they are younger than the Middle Cretaceous.

Inyan Kara.—This lone butte stands in Wyoming on the west side of the main uplift of the Black Hills. It has not been seen by the present writer except from a distance but has been described by both Winchell and Newton. As Newton's visit was the more recent we quote his description almost entire:[1]

Its name first appeared on a map published by Lieut. Warren in 1858, and as translated for him, signifies "the peak which makes stone." Its summit is 6600 feet above the sea, and has an elevation of 1300 feet above the bed of the Inyan Kara Creek near by. The igneous mass of the peak occupies the center of what in form resembles a crater, for separated from it by an annular valley there is an encircling ridge or rim whose top is 500 feet below the summit of the peak. This rim is formed of Red Bed limestone rising up from under the surrounding red clays at an angle of about 40° and completely encircling the peak except at a narrow break on the northeast side where the drainage escapes. The limestone wraps around the outer slope of the peak like a cloak, conforming to all local changes of dip and is without fracture. The upper red clays of the Red Beds lay up against this limestone, and in conformity with it dip away in all directions. On the inside of the rim is the annular valley, surrounding the igneous nucleus and having a width, from rim to center of peak, of from one-half to three-fourths of a mile. It has evidently been formed by the denudation of the easily eroded strata beneath the limestone.

From the midst of the crater-like depression the peak rises so abruptly that there is but one side with an easy slope for climbing. The summit is a broad but very irregular area, whose

[1] Geology of the Black Hills, pp. 197–199.

larger dimension has a bearing of about 30° West of North and upon which the rock is well exposed. It is a hard, highly feldspathic trachyte, and on weathered surfaces large and well formed crystals of feldspar were seen in great abundance, giving the weathered mass a porphyritic appearance. Its mass is notably magnetic. The rock shows well marked cleavage or jointing planes, nearly vertical, in two series. The first runs toward the northwest and the second towards the west, dividing the rock into prisms and producing a quasi-columnar structure.

Though on such a large scale, the entire upheaval being probably two or three miles in diameter, the peak has essentially the structure of the Sun Dance hills. Among the uplifted beds surrounding Inyan Kara no strata were recognized excepting Red Bed limestone and the underlying, impure, reddish sandstone, and beyond the immediate base of the outer slope no disturbance was indicated. Indeed, the red arenaceous clay is too nearly structureless to retain readily such evidence.

The high angle at which the stratified rocks surrounding the base of Inyan Kara dip away in all directions from the central core, shows that there was more disturbance caused by this intrusion than in any of the similar examples previously described in this paper. The igneous rock was also forced to a higher level than in the Sun Dance hills, and was greater in mass than in any of the similar hills in the neighboring part of Wyoming, with the exception of Mount Warren.

Complete as is the exposure of the igneous rock in Inyan Kara, it is to be remarked that no expansion of the central plug so as to form a coulee or a laccolite, is mentioned by the geologists who have examined and described it.

Bear Butte.—On the northeast side of the Black Hills and about six miles east of the town of Whitewood, there is another conspicuous butte, similar in many ways to Inyan Kara. This hill, known as Bear Butte, rises from Middle Cretaceous shales but is surrounded at its immediate base by older rocks which dip away in all directions. It has been described by F. V.

Hayden,[1] N. H. Winchell[2] and Henry Newton,[3] and from these descriptions the following has been compiled.

The butte rises 1200 feet above the surrounding plain and attains an elevation above the sea of 4570 feet. As seen from the north, it is a simple cone, but from the east and west summit appears as a ridge several hundred feet in length, with a trend about North 40° West. The strata which are exposed about its base and dip away from it in all directions, are composed of rocks of all ages from the Middle Cretaceous to the Potsdam, inclusive. A dense quartzite, probably of Potsdam age, occurs at the immediate base of the butte in vertical strata, but does not form a continuous circular outcrop.

The rock of which the butte proper is composed is very similar if not identical with that forming Inyan Kara, Bear Lodge, etc. It is crossed by cleavage plains but is not columnar. When freshly broken it is gray in color but when weathered it appears nearly black. The débris in the immediate vicinity of the butte is so abundant that good exposure of the stratified rocks surrounding its base are seldom seen. The harder beds in these strata, however, influence the relief sufficiently to show the presence of an encircling rampart of the same character as the much more conspicuous one, about the base of Inyan Kara. Denudation has stripped the central plug of igneous rock of its enveloping stratified beds almost as completely as in the case of the great tower in the valley of the Belle Fourche.

Crow Peak.—This peak is situated in the northern part of the Black Hills, about five miles west of the town of Spearfish, and rises to an elevation of approximately 1,500 feet above bottom of the Red Valley, which skirts its northern base.

It is described by Newton,[4] as a pustular outbreak of igneous rock through Red Bed limestone. As seen from the west it appears as two peaks closely united; the southern one is the

[1] Trans. Amer. Philo. Soc., Vol. XII., n. s., 1863, p. 28.

[2] Reconnoissance in the Black Hills, pp. 55–56.

[3] Geology of the Black Hills, pp. 195–197.

[4] Geology of the Black Hills, pp. 194–195.

rhyolite core, while the northern one is a portion of a rampart of sedimentary beds which once entirely surrounded it. This hill, like the others in the series to which it belongs, owes its existence, if the present writer's views are correct, to the intrusion of a plug of igneous rock vertically upward through nearly horizontal sedimentary beds and the subsequent exposure of the intrusive rock by erosion.

Terry and Custer Peaks.—These are other prominent landmarks in the northern portion of the Black Hills. They have been described by Newton,[1] as pustular outbreaks of igneous matter and belong to the series of intrusions to which attention is here directed, but so far as one can judge from the published descriptions, they offer no important features not already noticed in this paper.

Warren Peak.—This is the largest and in fact the only truly mountainous mass of igneous rock on the outskirts of the Black Hills, and may differ materially in the mode of its formation from the plugs of crystalline rock we have already noticed. Its broad extent and the manner in which the surrounding stratified rocks dip away from it in all directions, seems to indicate that it is a true laccolite, very similar to those of the Henry Mountains. The description given below is copied from Newton.[2]

Warren peaks are the crowning points of the "Bear Lodge Range," an elevated, broken plateau between the Redwater valley and the Belle Fourche. The peaks are not remarkably prominent, but their total elevation above the sea, 6830 feet, is equal to that of some of the principal peaks in the central portion of the Black Hills, while their height above the Red Valley immediately south, is about 1800 feet. The trachytic area to which they belong is the largest of the whole group, and covers fifteen or twenty square miles. Around this the strata of the sedimentary series are uplifted and arranged in concentric circling outcrops, so as to make a sort of miniature copy of the hills. The trachytic nucleus has an extension from northeast to

[1] Geology of the Black Hills, pp. 192–194.

[2] Geology of the Black Hills, pp. 199–200.

southwest of about eight miles, and a width of two or three miles. Its surface consists of high, rounded, grass-covered hills, with little or no timber, and from this rise the two or three more elevated points to which the name Warren peaks has been applied. These more central points are surrounded by smaller and less prominent peaks, which are separated by deep ravines or gulches forming the lines of drainage. Besides this great nucleal mass of igneous rock, several outbursts, very local in character, were observed in the zone of encircling strata. The rock is a trachyte, dark gray in color, and containing frequently large and perfect crystals of sanadine which give it a porphyritic character. Small crystals of mica and hornblende are also prominent, and the rock yields more to weathering than that of some of the other peaks. In different portions of the district the rock varies somewhat in its character, though evidently of the same general nature.

The encircling zones of sedimentary rocks include the Potsdam below and the Jura above. Their dip is quaquaversal and is usually quite regular, the angle varying from 20 to 30 degrees.

The Potsdam sandstone which immediately overlaps the base of the igneous mass has been greatly metamorphosed. When the rock was shaly it has been changed into a hard fissile slate, scarcely recognizable as of sedimentary origin; and the pure sandstone strata have been converted into compact quartzite often of a very white color. In several places the igneous matter seems to have penetrated between the strata, which are scarcely distinguishable from the injected rock, and in many cases the metamorphosis appears to have been performed by the action of heated waters, for the sandstone was found penetrated irregularly by well-formed crystals of feldspar. On the west side, near the middle of the formation were found layers of argillaceous sandstone covered by large branching fucoids peculiar to the Potsdam, and some of the upper layers of the sandstone are perfectly riddled with Scolithus holes. The Potsdam, Carboniferous and Red Beds are well exposed in many of the canyons which radiate from the central area carrying the drainage eastward to the Red-

water, or westward to the Belle Fourche. On the south and east, facing Sun Dance hills, the Red Bed limestone forms the outer slopes, dipping under the red clay of the Redwater Valley. On the north and west, however, the Jura is well exposed and capping this the Dakota sandstone.

Though on a grander scale and exposing a larger area of igneous rock than the other neighboring centers of intrusion, the Warren peaks show the same character of pustular eruption.

In a recent paper on the geology of the Black Hills, W. O. Crosby,[1] has devoted a few pages to the consideration of the igneous intrusion described in this paper, in which it is claimed that they are true laccolites. He also presents reasons for concluding that the hypothesis of "Pustular Eruptions," advanced by Newton is not warranted by the facts.

As I am unfamiliar from close inspection with the larger igneous masses of which Warren, Terry and Custer peaks are leading examples, I am unable to offer an opinion as to whether they are laccolites or not. Their great size and the manner in which the surrounding sedimentary beds have been disturbed and altered in their vicinity, certainly seem to indicate that such was their mode of origin. In the case of the Sun Dance hills, Mato Teepee and the Little Missouri buttes, however, which I have examined and also in the case of Inyan Kara and Bear Butte, which I have seen from a distance, and of which detailed descriptions have been published, the evidence does not sustain the assumption that they are laccolites.

The absence of volcanic débris except in the immediate vicinity of these hills, indicates that the intruded rock did not spread widely among the stratified beds or overflow the surface. This, as well as the fact that in a series of examples ranging through all degrees of erosion from the unbroken dome of Little Sun Dance hill to Mato Teepee with its majestic tower over 600 feet high, and Bear butte, 1200 feet high, neither of which exhibit evidence of laccolitic expansion, seems sufficient to prove

[1] "Geology of the Black Hills of Dakota." Boston Soc. Nat. Hist., Proc., Vol. XXIII., pp. 488–517.

that they cannot be referred to the class of intrusions that has its type in the Henry Mountains.

What precise mode of origin Newton had in mind when he compared these intrusions to bubbles in a viscid lava mass, is not clear. As the nature of laccolites was not understood at the time of his exploration, a comparison with that form of intrusion could not be made.

That the magma composing the hills described in this paper was cooled slowly at a considerable distance below the surface, and consequently under great pressure, is indicated by their geological associations and is proven also by the character of their crystalline structure. They are coarse grained or porphyritic, instead of being glassy and imperfectly crystallized. In no instance has the rock assumed the form of obsidian, pitchstone, pearlite, etc., or been expanded into scoria and pumice, as one would expect had the magma cooled at the surface.

None of the plutonic plugs examined by me are associated with dikes or faults. In fact dikes appear to be wanting in the Black Hills region, since they do not seem to be mentioned by any of the geologists who have written concerning it. It is reasonable to suppose that the magma which rose from below and formed the plug-like intrusions described above, found its way through fissures in the lower series of stratified rock, but proof that this was the case is wanting. How the stratified beds below the domes that covered the plugs were displaced, or perhaps fused, so as to furnish room for the passage of the intruded material, is not clear.

A comparison of the structure of the Sun Dance hills, Inyan Kara, etc., which are from one to two or three miles in diameter, with the structure of the dome that once covered Warren Peak, and had a diameter in one direction of two to three miles, in another direction of about eight miles and a height of two or three thousand feet; and still again with the structure of the vastly greater dome from which the Black Hills, as we know them, were sculptured, brings out striking similarities. Had no erosion taken place since the Black Hills uplift began, as is shown

in a contour map by Newton and Gilbert,[1] it would now form a great, elongated dome, about 80 by 160 miles in diameter, and rising 7000 feet above the encircling plain. The central core of this vast dome is composed of schist and granite, from which the surrounding sedimentary beds dip away in all directions in the same manner as they do about the Sun Dance hills.

Great as is the Black Hills dome, it is far surpassed in size by a similar uplift forming the Big Horn Mountains, rising some 180 miles to the westward, and by several of the ranges in the Park Mountains, Colorado.

Some of the thoughts suggested by these and other comparisons, with reference to the origin of great domes in a broad region of horizontal rocks, will be presented in a future paper in this JOURNAL.

ISRAEL C. RUSSELL.

[1] Geology of the Black Hills, Pl. *cf.* p. 208.

THE GEOLOGY OF NEW HAMPSHIRE.

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THE first public notice of the importance of examining the mineral resources of New Hampshire is contained in a message of Governor Levi Woodbury to the legislature in 1823. He recommended the institution of an agricultural survey with a view to chemical analyses of the various kinds of soils. Had this recommendation been adopted, New Hampshire would have been the first of the United States to inaugurate a scientific survey of her mineral resources.

The First Geological Survey.—In 1839, after earlier suggestions from the executive, the legislature passed an act to provide for the geological and mineralogical survey of the state, appropriating for the purpose the sum of two thousand dollars annually for three years. Dr. C. T. Jackson, of Boston, received the appointment of geologist, and with several assistants conducted the work of the survey, and published the following reports:

First Annual Report on the Geology of the State of New Hampshire, 8vo, 164 pp., 1841.

Second Annual Report on the Geology of the State of New Hampshire, 8vo, 8 pp., 1842.

Final Report on the Geology and Mineralogy of the State of New Hampshire, with contributions toward the improvement of Agriculture and Metallurgy, 4to, 378 pp., 11 plates, 1844.

Views and Map of the Final Report, reprinted, 4to, 20 pp., 8 plates, 1845.

The character of this final report may be summarized as follows: 44 per cent. of the pages is occupied with a description of the method of procedure and notes upon the geological and mineralogical results in the form of an itinerary; 20 per cent. relates to economic geology; 22 per cent. to agricultural geology and chemistry, and the remaining 16 per cent. is devoted to such miscellaneous topics as barometrical tables, the official documents relating to the survey, glossary and index. One of the assistants, was Professor J. D. Whitney, of Cambridge; Dr. E. E. Hale, of Boston, aided in the exploration of the White Mountains.

The method of exploration or reconnaissance adopted by Dr. Jackson was based partly upon the structure. Knowing that the strata pursue a general northeast course, it was proposed to cross them several times at right angles to their outcrops, and also along the lines of strike. These lines divided the territory into triangular areas whose outside boundaries became known, and the various excursions for study were planned across several tracts, depending somewhat upon roads and settlements. Four cross sections are described and figured, viz., from Portsmouth through Concord to Claremont; from Concord to Wakefield; from Concord to Winchester; from Winchester to Haverhill. There is also a longitudinal section along the Connecticut River from the Massachusetts line to Haverhill; and from Haverhill to the extreme northern part of the state. Six distinctions are made: (1) Granite, syenite and gneiss; (2) mica slate; (3) hornblende rock; (4) argillaceous slate; (5) drift; (6) alluvium. Symbols indicate the location of twenty kinds of ores and minerals, quarries, dips of strata and anticlines.

The nature of the work was mineralogical. Scarcely any assistance was acquired from these reports for the later geological studies. The general view of age and structure presented was that of the older authors, all granite being regarded as "Primary," and the dips of the strata outward in every direction from an igneous center. This conclusion is best shown in an ideal section across northern New England. At the White

Mountains granite prevails, having mica slate and gneiss dipping to the east in Maine; similar rocks occur on the west side, together with "Cambrian," all inclined towards Lake Champlain. The Green Mountains are made out to be an immense mass of quartz rock. There seems to be an important element of truth in this representation, while the details cannot be relied upon. In the neighborhood of the White Mountains the older rocks make their appearance, but granite does not constitute the central axis of the White Mountains; the strata are not uniformly regular in their dips outward from the axis, and the Green Mountains are not made of quartzite.

It is difficult to find accurate reports of the cost of Jackson's survey, but it would appear probable that the explorations and studies cost less than $10,000, and the expense of publication was met by other appropriations. Owing to the wish to reduce the size of the last item of expenditure, the map has no coloration, so that it is difficult to pronounce upon its value.

The Second Geological Survey.—In 1868 the legislature passed an act providing anew for the geological and mineralogical survey of the state, for which the sum of $3500 was annually appropriated. It was stipulated that brief annual reports showing the progress of the survey should be made, and "when the survey shall be completed, a report of the same, accompanied by such maps and drawings as may be necessary to elucidate and exemplify the same, shall be published under the direction of said state geologist."

On the eighth of September 1868 the writer was appointed state geologist by Governor Walter Harriman. The work was prosecuted for ten fiscal years, the time used for exploration being somewhat less than would appear from the records. So far as the survey had a connection with the state government, its enabling act carried two favorable provisions: (1) It was not necessary to go before the legislature every year with a request for a new appropriation. If this had been the case, probably the life of the survey would not have extended beyond three years. (2) Only brief reports of progress were expected annually.

I have taken great pains to determine exactly the cost of every part of this survey to the state, including the explorations, printing the annual and final reports, but not the cost of distribution.

Expenses of exploration and study, - -	$32,199.27
Annual reports (1500 copies), - - -	1,459.80
Final report (1000 copies), - - - -	33,959.17
Relief map and cases for museum, - -	500.00
	$68,118.24

The following titles express the official reports to the state:

First Annual Report upon the Geology and Mineralogy of the State of New Hampshire, by C. H. Hitchcock, state geologist, 12mo, 36 pp., 1 map.

Second Annual Report upon the Geology and Mineralogy of the State of New Hampshire, by C. H. Hitchcock, state geologist, 8vo, 37 pp., 1 map.

Report of the Geological Survey of the State of New Hampshire, showing its progress during the year 1870, by C. H. Hitchcock, state geologist, 8vo, 82 pp.

Report of the Geological Survey of the State of New Hampshire, showing its progress during the year 1871, by C. H. Hitchcock, state geologist, 8vo, 56 pp., 1 map.

Report of the Geological Survey of the State of New Hampshire, showing its progress during the year 1872, by C. H. Hitchcock, state geologist, 8vo, 15 pp., 1 map.

The Geology of New Hampshire. A report comprising the results of explorations ordered by the legislature, by C. H. Hitchcock, state geologist, J. H. Huntington, principal assistant. Part I. Physical Geography, Royal 8vo, 680 pp., 49 plates, 1874.

The Geology of New Hampshire, etc., by C. H. Hitchcock, state geologist, J. H. Huntington, Warren Upham, G. W. Hawes, assistants. Part II., Stratigraphical Geology, Royal 8vo, 696 pp., 40 plates, 1877.

The Geology of New Hampshire, etc., by C. H. Hitchcock, state geologist, J. H. Huntington, Warren Upham, G. W. Hawes, assistants. Part III., Surface Geology. Part IV., Mineralogy and Lithology. Part V., Economic Geology. Royal 8vo, 760 pp., 30 plates, 1878.

Atlas accompanying the report on the Geology of New Hampshire, by C. H. Hitchcock, state geologist, 1878. Folio containing seventeen maps and profiles.

Peculiarities of this survey.—Geological surveys may be classified in groups. Those prosecuted in the same decade will be

found to be very much alike. The surveys more or less coeval with that of New Hampshire, 1868 to 1878, were the following: Canada, where the directorship was transferred from Sir W. E. Logan to A. R. C. Selwyn in 1870; the geographical and geological work in the territories under F. V. Hayden extending from 1867 to 1878; the fortieth parallel survey under Clarence King, 1867 to 1880; the Wisconsin survey, T. C. Chamberlin, 1873 to 1879; the Michigan survey, 1869 to 1876, under Rominger, Brooks and Pumpelly, and the Ohio survey under Newberry, 1869 to 1878. The second geological survey of Pennsylvania began in 1874, and that of Minnesota in 1872. It was an honor to any geologist to have been a contemporary worker with the gentlemen who directed these several surveys. But the style of work in vogue then should not be expected to equal that which is being executed in the nineties, with the multitudinous facilities of the later period.

The new methods of petrographic study were first exemplified in these surveys by the report of Ferdinand Zirkel upon Microscopical Petrography for the Fortieth Parallel organization in 1876, and by Dr. G. W. Hawes upon the Mineralogy and Lithology of New Hampshire in 1878. Both of these treatises were models in their way, and were carefully studied by workers in this field for many years. Mineralogists not connected with surveys engaged in corresponding studies even earlier. Dr. Hawes continued his investigations into some of the New Hampshire rocks after the publication of his report, as is evidenced by his descriptions of the contact phenomena between the Albany granite and mica schist upon Mount Willard, and upon the dissimilar dikes found at Campton. His early death cut short a most promising career.

The progress of the New Hampshire survey was much retarded by the presence of a dense forest covering an area of 2000 square miles in the northern portion of the state, and by the difficulties of transportation. All this mountainous forest had to be traversed on foot mostly without paths or guides. From the summit of Mount Washington a sea of mountains is visible. Every one

of them was visited by some member of the survey, observations made and specimens preserved for study. At the present time railroads thread three-fourths of this forest country, and by excavations and the removal of the forests, facilities for exploration have been greatly increased. Had the survey of this region commenced fifteen years later, the information acquired could have been gathered in a fourth part of the time actually taken.

Connection with work in adjoining territory.— The geology of New Hampshire is intimately connected with that of Vermont and Canada. The writer had fortunately been connected with the survey of the former as principal assistant, and was familiar with what had been published for both adjoining districts, and had taken pains to revisit typical and extra-limital areas during the progress of the explorations. The published New Hampshire map covers fully a third part of eastern Vermont and an important section of Canada, for which information was based upon a manuscript left by Sir W. E. Logan, interpreted in the light of later studies. The chief support of our stratigraphical conclusions lay in the anticlinal structure of the Green Mountains. My advisers, Professor James Hall, Sir W. E. Logan, and Professor J. D. Dana, taught me that this structure was synclinal. After measuring thirteen general sections across this range, it became clear that my guides were in error. Their great anxiety to maintain the synclinal notion had been exerted in order to sustain the doctrines of the metamorphism of the crystalline rocks and their Palæozoic age. With the determination of the anticlinal attitude quite a different interpretation of age resulted, as well as less respect for the theories that had led my masters astray.

A word in reference to the determination of this structure. C. B. Adams in his Annual Reports (1846–8) states the questions at issue in respect to the age of the crystallines, without endorsing either view. Having noted the existence of quartzite and limestone in Plymouth upon the east side of the range, he queries whether these rocks may not be repetitions of the granular quartz and Stockbridge limestone. Other facts show that Adams favored the metamorphic view—and it is supposed influ-

enced his successor Zadock Thompson to draw up an elaborate section along the Winooski River between Burlington and Waterbury, exhibiting a fan-shaped stratification. After taking charge of the Vermont survey, my father commissioned me to measure and protract on paper the thirteen general sections across the state. From these plans he drew various conclusions, including the anticlinal attitude of the Green Mountains, without referring either to his theoretical Hoosac section of 1847, or to the Canadian belief in a synclinal, or to its importance in the development of the more eastern terranes. Since 1861[1] I have several times insisted upon the fact and its importance, maintaining at first that Logan's description of Sutton Mountain favored the anticlinal view. Selwyn corrected Logan's error in 1877. Professor Dana acquiesced in this view in 1882. Of late it has been confirmed by Professor Pumpelly[2] for the Hoosac Mountain, and by Mr. C. L. Whittle[3] for the range at Mt. Holly. At my first visit to Montreal (1857) Sir W. E. Logan referred the chief part of Canada adjoining Vermont to the Oneida conglomerate. After 1860 he devised the "Quebec group," subdivided into the Levis, Lauzon, and Sillery formations, supposed to be allied to the Calciferous and Chazy. It was his coloration of the maps next the international boundary, classified into these three divisions, that I copied on my map of New Hampshire as part of the Huronian, or the hydro-mica schists. In my first two annual reports I used the name of Quebec for these rocks, changing later at the instance of Dr. Hunt, who claimed them to be partly, at least, older than Cambrian, or equivalent to the Huronian of Ontario. Our use of terms was dependent upon the terminology employed by our Canadian neighbors, as they were the originators of the various expressions employed. Still another modification of the nomenclature will be presently alluded to.

Topographical results.—The map in our atlas was drawn upon

[1] Geological sections across New Hampshire and Vermont, Bull. Am. Mus., N. Y., Vol. I., 1884.

[2] Geology of the Green Mountains in Massachusetts. Monograph XXIII. of the U. S. G. S.

[3] JOURNAL OF GEOLOGY, Vol. II., p. 296.

the scale of two and one-half miles to the inch, to match the Massachusetts work of Simeon Borden in 1842, adding to his delineations approximate contours for every hundred feet. It was based upon the United States government map of the international boundary (1842), special triangulation under our direction, the early and late determinations of the United States coast and geodetic survey, combined with detailed compilations from the county odometer road surveys. Without pretense to special merit, it has been pleasant to us to compare the best parts of this map in the White Mountains and the southeast part of the state with the beautiful sheets of the United States geological survey, when enlarged to their scale. That experts should at first have placed higher value upon this map than it deserved is not the fault of its compilers.

DETERMINATION OF THE ORDER OF THE GROUPS OF SCHISTS.

In establishing the New Hampshire stratigraphical column the attempt was first made to construct it independently of the existence of similar rocks elsewhere. Certain principles were accepted as well established. One of them was that crystalline schists constitute stratified formations, capable of being identified in different districts by their mineral composition. Among the groups capable of ready recognition were the following: gneiss, ordinarily consisting of the three constituent minerals, quartz, feldspar and mica, with no accessories; and this was termed *common*, or from a locality, *Lake Winnipisoegee* gneiss. This for convenience was shortened to *Lake* gneiss, and seemed to be equivalent to the lower part of the Green Mountain series. In another area mica was replaced by chlorite, giving rise to chloritic gneiss, protogene or locally *Bethlehem* gneiss. Another peculiar variety was termed *Porphyritic*, corresponding to the *Augengneiss* of Central Europe. The occurrence of large crystals of feldspar seemed to be more noticeable than the presence of black spots with the white, producing a resemblance to eyes. It was also found that sometimes this porphyritic rock was devoid of foliation — the crystals were disposed at random instead of being arranged in

lines—and our observations were never extended so far as to be able to declare that these differences were of importance.

Of the mica schists one range abounded in *fibrolite*, a second in *andalusite*, and a third in *staurolite*. No two of these minerals were combined in the same set of schists, while all the bands are related to one another. The *hydro-mica-schist* group contained associated bands of chlorite schist, quartzites, bedded diorites, diabases and protogenes; and had before our time been known as "talcose slate." No local term was applied to this complex, as it was supposed to represent the *Huronian* group of Canada, with which it had strong points of resemblance. *Hornblende-schist* proved to be common, and, with some misgiving, was relegated to the base of the hydro-mica groups. These several groups of schists were believed to belong to as many distinct periods of growth, each with its peculiar conditions.

Inasmuch as the formations possessed northerly trends, sections in east and west lines would most economically represent their structure, and hence the Dartmouth museum has a special large case prepared upon which fifteen sections are arranged in geographical order extending from Maine to New York across New Hampshire and Vermont. This collection contains about 3000 specimens, which are still further elucidated by geologically colored profiles and a large relief map.

A second principle employed was the discovery that the crystalline schists of New England tended to assume ovoidal shapes exhibiting a banded structure. Reference was made to the groups of Percival in Connecticut, K_1, K_2 and K_3, as well as to the B of the Eastern Primary. The center of the oval seems to be the oldest part. Dr. A. C. Lawson[1] describes similar areas in the Rainy Lake district north of Lake Superior, as does Professor A. Winchell[2] in Minnesota and Professor B. K. Emerson[3] in western Massachusetts.

As there is no readily recognizable base to the New Hampshire rocks, it was found necessary to fix upon some convenient

[1] Ann. Rept. Geol. Can., 1887.

[2] Bull. Geol. Soc. Amer., Vol. I., p. 361.

[3] *Ibid.*, p. 559.

starting point where the succession seemed obvious. The horizon selected was the superposition of hornblende-schist upon gneiss. My first work of a stratigraphical nature had been the study of a low anticline of this nature at Shelburne Falls, Mass.[1] At the base was a well defined gneiss, capped in succession by hornblende-schist, mica-schist and the same with interbedded limestones.[2] The first two rocks occupied quite a small area, and were exposed only through denudation. On proceeding northerly similar relations of gneiss and hornblende-schist were seen upon several of our sections. Hence the generalization, hornblende-schist overlies gneiss. The next point was to follow out the distribution of these two rocks. The gneiss of the Halifax-Hartland range proved to be a well-defined geanticlinal sixty miles long, dipping westerly to reappear in the Green Mountain gneissic area, and dipping easterly to reappear in the gneisses of Cheshire, Sullivan and Grafton counties, traceable for over one hundred miles with a westerly dip. On traversing the country to the east still other gneisses appear. Hence the second generalization, there exist several parallel anticlines of gneiss, connecting the Green Mountain and Lake areas. But two of these ranges cover an area of porphyritic gneiss, between Jaffrey and Groton, sixty miles in length, thirteen miles in its greatest breadth, following the height of land between the Connecticut and Merrimack rivers. Its stratification is obscure, while the representation of the dips upon the six revised sections crossing it, conform to the notion of its inferior position. Nothing has been found underlying this rock, so that it must be considered as the base of the crystalline succession for New England. More than twenty patches of this basal gneiss occur in the state, a few carrying fibrolite schist and one contains fragments of a dark gneiss—possibly an older layer.

The place of the chloritic (Bethlehem) gneiss is not so readily determined. It occurs only on the east slope of the Connecticut

[1] Proc. Boston Soc. Nat. Hist., Vol. VI., p. 330.

[2] Upon the Hawley sheet Professor Emerson describes the same succession, using the local names, Becket gneiss, Hawley amphibolite, Goshen schist and Conway schist.

Valley in six or eight isolated areas, interspersed over a distance of a hundred and twenty-five miles, and covered by hornblende-schist occasionally. It has been located between the porphyritic and lake gneisses. The hornblende schist does not guide us satisfactorily to the upper formations; and hence other considerations must be taken into account in the further attempts at classification. Most of the remaining rocks are some form of mica schist. They are plainly above the gneisses, for wherever any of them come in contact with the feldspathic rocks they are superincumbent. They have been distinguished as the *Montalban*, or mica schists carrying some feldspar with fibrolite or andalusite; the group of *hydromica schists; Rockingham mica schists; Merrimack group* and *Ferruginous slates.* After detailed studies our conclusion was that the Montalban preceded the hydromica schist which were closely related to the Kearsarge and Merrimack schists and the Ferruginous slates of Hillsborough county. The Rockingham schists simulated the Montalban.

The hydro-mica schists are arranged primarily in two divergent lines, which are assumed to represent one grand formation, whatever its place in the scale may be. The best known is that which starts in western Massachusetts under the old name of talcose schist, passes through central Vermont east of the Green Mountains and continues past Quebec parallel to the St. Lawrence River. Both the Vermont and Canada surveys recognized a similar (third) belt on the west side of the Green Mountains, extending as far south as Middlebury. The eastern line begins at Bellows Falls and is nearly continuous along the Connecticut to the mouth of the Passumpsic River, and thus expands to as great a width as that of the central belt, and it continues through the western edge of Maine into the Gaspè peninsula. Ranges of gneiss flank both these hydro-mica belts, viz., the Green Mountain gneiss upon the west and the Connecticut band of lake gneiss on the east, and with the same synclinal disposition. Inside of the hydro-mica schists are belts of argillite, which seem to follow the same synclinal law of distribution. There is left between the argillites an immense area which has

been designated the Calciferous mica schist, and it naturally completes the filling of the basin. This is the formation that was described in my Shelburne Falls section in 1858, with the same two divisions. There is a great development of rocks related to the lower division along the Connecticut Valley that were presumed to represent the lower part of the Calciferous, and they received the name of Coös group, consisting of a basal quartzite, mica-schists, hornblende-schists, staurolite-mica-schists and slates, several thousand feet in thickness. The early Canadian reports regarded the Calciferous schists as of Niagara age. Our report regards all these schists as the most modern of the stratigraphical column, but does not insist upon their identity with the beds carrying fossils.

An important chapter would relate to the discovery of fossils in New Hampshire. They were found at Littleton in 1873 and referred to the Lower Helderberg by E. Billings, palæontologist to the Canadian survey. Later discoveries have proved the Niagara age of the enclosing rock, because of the presence of *Halysites* or chain coral and *Pentamerus nysius*. The rocks connected with the fossils are limestones, slates and sandstones, more like the Coös bands than the Calciferous. They have been followed down the Connecticut to connect with the fossiliferous limestone and sandstone of Bernardston, Massachusetts, belonging to the Devonian. Niagara fossils are also known from the west shore of Lake Memphremagog.

The column thus established from structural evidence consists at the base of the porphyritic or *Augengneiss* followed by the Bethlehem or chlorite gneiss, and the ordinary lake gneisses, amounting to at least 28,000 feet in thickness, if foliæ are to be esteemed capable of measurement. In the view of the report, the immediately ensuing 12,000 feet of gneissic-mica schists or Montalban occupied an intermediate place between the gneisses and the hydro-mica-schists. These last were subdivided in the Connecticut belt into the Libson chlorite schist, the Lyman argillitic (*Urthonschiefer*) schist and the auriferous conglomerate, in all 12,000 feet thick. In the central belt the triple classifi-

cation of Logan into the Levis, Lauzon and Sillery was recognized. In the central and southern part of the state was a great development of mica-schists of about the same thickness, called locally the Rockingham, Kearsarge and Merrimack groups. The well recognized Palæozoic rock of the northern parts of the state foot up about 16,000 feet, and were named the Cambrian slates, Coös group, Calciferous mica schist and the Lower Helderberg.

Correlation with recognized standards.—Having established an order of succession, our next effort was directed to their correlation, with the generally recognized sequence elsewhere. In Canada the order was that of Laurentian, Labrador, Huronian and Cambrian; in southern New England no satisfactory determinations were available. The porphyritic gneiss naturally allied itself to the *Augengneiss* of the Laurentian of Canada and elsewhere. The Bethlehem gneiss had more affinities with the same group than any other; and we were fortified in our conclusions by the independent and unsolicited opinions of Professor J. D. Dana and Dr. T. Sterry Hunt. It was difficult to know where to place the lake gneiss, if not in the same general group. The Manchester and Berlin ranges rendered this reference easy because of their saccharoidal character. Other areas contained beds of magnetite, limestone and plumbago, but none of the Adirondack pyroxenic rocks occurred in any of them. Hence, the three schistose groups would seem to correspond in general with the Ottawa and Grenville divisions of the Canadian Laurentian. While referring the gabbros to the Labrador system, it was expressly stated that they could be regarded only as an igneous rock, and hence not properly a stratified system.

If these gabbros represented an igneous action occurring in the later Laurentian of Canada, then the schists penetrated by them in New Hampshire must have been equally ancient or Archæan. Hence the origination of the term *Montalban*, representing a terrane younger than the Laurentian and older than the Huronian.[1]

[1] This does not correspond to the signification attached to this word later by Dr. T. Sterry Hunt.

As thus defined the New Hampshire Montalban is like the *Coutchiching* division of Ontario, proposed by Professor A. C. Lawson for a system that occupies just this horizon.

The hydro-mic-aschists and associated diabases, etc., corresponded well petrographically to the Huronian complex, and were so referred. At first it was thought that our White Mountain porphyries might be referred to the lower Huronian or Arvonian of Dr. Hunt, but the reasons demanding the removal of the gabbro from the stratified systems prevailed equally well as applied to the porphyries.

As to the various mica-schists and related rocks, called locally Kearsarge, Merrimack and Rockingham, no satisfactory reference could be made; and hence they were called Palæozoic in general, their alliance being obviously Huronian or Cambrian. The argillites were all referred to the Cambrian, having in mind the fact that this seemed to be the place for rocks of this class, whether in Vermont (Georgia), Massachusetts (Braintree), or Nova Scotia. The Coös quartzites, schists and slates, also the Calciferous mica schists all received an assignment to horizons superior to the Cambrian.

An improved classification.—The question now arises, How can our early classification be improved? It is eighteen years since the New Hampshire report was published, and there are many new workers in the field, all placing great reliance upon petrographical principles, such as were inaugurated in Dr. Hawes' report. Some are advocates of extreme metamorphism, and hence the conclusions are not harmonious. It seems to us that our early views may be modified by the following principles: (1) The mineral characters of crystalline rocks are not a sure guide to geological age. (2) Protogenes, diabases and diorites more or less interstratified with hydro-micas are of true igneous origin. (3) The Archæan gneisses and protogenes may also be of igneous origin, and their apparent stratification has no connection with sedimentary or chemical deposition. (4) The Huronian[1] era may properly represent the beginning of sedi-

[1] There seems to be no need of introducing a new term—Algonkian—to replace

mentation. The first sediments must have been accompanied by a greater flow of eruptives than those formed later. (5) Much of the hornblende-schist is igneous, related in origin to laccolites. (6) Serpentine and steatite are alterations of material originally igneous.

Applying such principles to the classification of the rocks of northern New England, we may improve on the report in several particulars. (1) Archæan rocks are not eliminated from our list. They exist as oval areas, such as have been indicated, in the Stamford gneiss and south of Mt. Killington, Vermont, in the Hinsdale, Massachusetts, area, the Hoosac Mountain, and elsewhere. I recognize the porphyritic gneiss in the Stamford rock and in the Hoosac tunnel as Archæan. (2) Our hesitancy about the place of the Bethlehem gneiss is met by recent observations. They are batholites, containing inclusions of the adjacent mica schists. It does not follow that all these protogene areas are of the same character; each one must be studied by itself. Some may be altered gneisses, and others sandstones where feldspar grains prevail. (3) Later observers are not agreed as to the nature of the upper part of the Green Mountain gneisses. What is apparently the same material is called "Cambrian gneiss" on Hoosac Mountain by Professor R. Pumpelly[1] and "Algonkian" by Mr. C. L. Whittle[2] near Rutland, Vermont, Professor Emerson in adopting Pumpelly's view finds a series of anticlinals of the same material further east, which probably correspond to the similar folds referred above to the lake gneisses. (4) Later conclusions respecting the age of the rocks entering Vermont and New Hampshire are entertained by the Canadian Geological Survey.[3] There are three areas of pre-Cambrian, viz., the axis of the Green Mountains; the Sherbrooke belt, reaching Lake Memphremagog, and along the international

Huronian. Better amend the latter so as to exclude the Cambrian, rather than cumber literature with a term harder to write, less euphonious, and with practically no difference of signification.

[1] Monograph XXIII., U. S. Geol. Survey.

[2] This JOURNAL, Vol. II., p. 396.

[3] Bull. Geol. Soc. Amer., Vol. I., p. 453.

boundary of New Hampshire and Maine. Associated with these older rocks are slates, sandstones and conglomerates believed to be Lower Cambrian. The continuations of the Calciferous mica-schists are termed Cambro-Silurian, because Trenton-Utica graptolites occur in them. Various limited outlying patches of Upper Silurian fossiliferous rocks rest upon the mica-schists. It is easy to connect these belts with their more southern developments. Some portions of what we have called Huronian are Pre-Cambrian, in the two diverging areas specified above, page 54. The two bands of argillite supposed to overlie the hydro-micas, the one reaching to Barnard and the other to North Hartland, are identical with the Cambrian of Ells, and there is complete agreement as to the order of succession of all the formations named between the two surveys. This argillite underlies the Calciferous mica-schist. (5) In this connection it is proper to say that recent studies enable me to trace the argillite of Bernardston, Mass., past Bellows Falls to East Hanover and Orford, and it is to be distinguished from the two ranges just named in Vermont, for it overlies the Calciferous, and is associated with the latest rocks of the Connecticut Valley, being perhaps Devonian. I have recently explored a mass of it in Littleton, N. H., which appears to overlie the Niagara. It was called Cambrian in part in the New Hampshire report, because it seemed to be the same with the slates of that age further west, while other portions carrying incipient staurolites and small garnets were denominated Coös slate. (6) A study of several areas of hornblende-schist proves that they are igneous. (7) The area of the Montalban about the Presidential range among the White Mountains proves to be less in amount than has been stated. Mts. Adams, Jefferson and even the top of Mt. Washington are composed of mica-schists like those occurring along the carriage road rather than the true gneisses. On Mt. Clinton the mica-schists carry fragments of other rocks as if they were an igneous paste carrying inclusions.

SURFACE GEOLOGY.

Few of the early state reports have discussed glacial phenomena so fully as that of New Hampshire. The glacial theory of Agassiz, and Dana's doctrines as to the origin of the modified drift in connection with the flooding of river valleys through the melting of ice were accepted to explain the facts obtained. Measurements of striæ were taken everywhere, whether upon the tops of mountains, scant forest exposures, or in valleys, their number much exceeding those taken by any other organization.[1] The most important conclusion derived, for which the territory is best adapted because of the great elevation of the land, is that during the maximum ice development the motion came from the northwest and was directed over the mountains southeasterly; or, in other words, from the St. Lawrence Valley up the northward slopes of the White and Green Mountains, and over them towards the Atlantic.[2] Striæ were noted upon the summits of nearly all the highest mountains, and where these were wanting transported erratics abounded. Later observations have shown some form of glacial work upon every summit and every col of the White Mountains. By way of confirmation of this doctrine, our latest unpublished observations show that remnants of the accompanying terminal moraines[3] had a northeast-southwest course, being at right angles to the normal direction of the ice-sheet. In other parts of the state, notably upon the seaward slope, the striæ appear to have been deflected by the topography; and still later evidence is presented to suggest the presence of local glaciers radiating in every direction from the higher mountains, pushing northerly and northeasterly into Canada as well as to the south. A few suggestions as to the diversity of the Ice Age were made, such as would now confirm the theory of Geikie. They consist in the advocacy of interglacial deposits in the valley of Lake Winnipiseogee and about Portland, Me., and in the existence of an

[1] Seventh Annual Report of the U. S. Survey, p. 157.

[2] Bulletin Geol. Soc. Am., Vol. V., p. 35.

[3] Proc. Amer. A. A., Sci., Vol. XLI., p. 173.

abnormally compact lower till under the ordinary ground moraine.

The writer can find no reference to the drumlins earlier than his own descriptions of Prospect Hill[1] in Andover, Mass., in 1867. It represented something accumulated by ice, but not an ordinary moraine. These hills received much attention in the report, hundreds of them having been mapped in the atlas. Their longer diameters were found to coincide with the direction of the ice movement; being generally southeasterly in Rockingham county, southerly west of Merrimack River, and west of south in the Connecticut Valley on the edge of Massachusetts. Mr. Warren Upham devoted himself to the exploration of these lenticular hills, and in searching for them beyond the limits of New Hampshire, became interested in the terminal moraines of Cape Cod and Long Island.[2]

Special attention was given to the modified drift in the report by Mr. Upham. The terraces of the Connecticut and Merrimack Valleys were carefully mapped and leveled, with the intention of testing the application of the marine or fluviatile theory of their origin. It would appear that the highest terraces and deltas of tributaries represent the remnants of the ancient flood plain where the river had its greatest volume. These remnants are quite uniformly nearly two hundred feet above the Connecticut River—whether at the state line on the south or at the mouth of the Passumpsic. Very commonly a tributary increases the height of the flood plain for a short distance. If the terraces had been made in a series of lakes, or at successive heights of the ocean, they should have been arranged in a series of steps from the sea upwards.

Eskers had been described in Maine, but it remained for Mr. Upham to bring them to light in all the principal New Hampshire valleys, especially in the Connecticut from Windsor, Vt. to Lyme, N. H., a distance of thirty miles. The main river cuts its way across this gravel ridge seven times, and it is quite concealed by terrace deposits in a part of its course.

[1] Proc. Essex Inst. Nat. Hist., Vol. V., p. 159.

[2] Geol. New Hampshire, Part III., p. 300.

The writer in accepting the diversity of the Ice Age, believes the Champlain to have been one of the glacial epochs. The name was originally given by him to the sands and clays bearing marine mollusca, with the accompanying deltas and terraces; and that includes terraces in the Champlain Valley, the south-flowing rivers and along the New England coast. The fossils indicated a glacial climate as far south as Massachusetts Bay, and a cooler climate in Nantucket. It was a time of differential depression, amounting to more than one foot to the mile in proceeding northward, so that sediments filled up rivers and compelled the renewed streams of today to find new channels for themselves over ledges. With a submergence of perhaps a thousand feet in the lower St. Lawrence and an arctic climate, glaciers would form on the Laurentides, Green and White Mountains, moving towards each other and discharging icebergs into the inter-island area. Mr. Upham [1] suggests that all the drumlins in the country were formed at this time. It was certainly true of those near Boston, as they contain not less than fifty-five specimens of marine temperate mollusca, which must have been transported as erratics to their present locations. Hence the climate of New England must have had an arctic character in the Champlain epoch.

As elsewhere suggested,[2] the writer believes the adoption of the view that the Champlain was a glacial epoch with the land much depressed, and a sea full of icebergs moving southwesterly from the Gulf of St. Lawrence, will enable the advocates of the glacier and iceberg theories to harmonize their conflicting opinions.

C. H. HITCHCOCK.

[1–2] Bull. Geol. Soc. Amer., Vol. VII

NORTH AMERICAN GRAPTOLITES:

NEW SPECIES AND VERTICAL RANGE.[1]

PREFACE.

No general revision of American graptolites has been attempted since the termination of Hall's classic labors some thirty years ago, and one based on the lines of recent taxonomic progress is badly needed. The present paper is a preliminary attempt at such a zoölogic and geologic revision.

The tables showing the vertical range of species are, to a considerable extent, based on my own determinations. This reservation is necessary, as many of the ranges assigned to species are incorrect, the result of erroneous identification. In this matter I am glad to find myself in general accord with Ami,[2] almost the only American observer who has studied extensively the graptolites in the light of recent foreign work.

A word as to the somewhat numerous changes made in the synonymy. Most of them are in accordance with general graptolite consensus. Most of the remainder are explicable on the ground of priority. In a previous paper[3] I followed general consensus rather than attempt the necessary thorough overhauling of the synonymy, reserving the latter until such time as I could publish more extensively the reasons for the requisite changes. Now, however, it seems best to enforce priority rigidly, and to this end the original spelling has been followed in all cases. Reasons for deviation from current usage are given in brief, but in a paper of this compass it is of course not possible to give the evidence in extenso.

No attempt has here been made to determine accurately the

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Bull. Geol. Soc. Amer., II., pp. 477–502, Plate XX.

[3] Ann. Rep. Geol. Surv. Ark. for 1890 (1892), III., pp. 401–418, Plate IX.

zoölogic limits of the group, as this paper being rather geologic than zoölogic, the aim has been to include every species of graptolite (as the word is generally understood), reported from American strata, with the proper generic reference and the ascertained range. Only species in good standing are, however, given, and such forms as *Nereograpsus*, which are no longer regarded by any one as graptolites, are omitted.

Finally, all new species here described will be fully illustrated in a future publication of the U. S. Geological Survey. The authority for each new species is appended to it.

I. DESCRIPTIONS OF GENERA AND SPECIES.

Phyllograptus Hall, 1858.

Rep. Progr. Geol. Surv. Can. for 1857, pp. 135, 137. Type, *P. typus* Hall.

Phyllograptus ? cambrensis Walcott, sp. nov.

"*Diplograptus simplex* (Emmons)" Walcott, 1886, Bull. 30, U. S. Geol. Surv., pp. 92–93, Plate XI., Figs. 4, 4*a*; "*Phyllograptus simplex* (Emmons)" Walcott, 1889, Amer. Jour. Sci., XXXVIII., p. 388.

The synonymic relations of this species are very complex. For the present it is sufficient that it is neither *Fucoides simplex* Emmons, 1844 (*Taconic System*, p. 27, Plate V., Fig. 1), nor *Diplograpsus secalinus* (Eaton) Emmons, 1856 (*American Geology*, I., Part II., p. 104, Plate I., Fig. 11).

Bryograptus Lapworth, 1880.

Ann. and Mag. Nat. Hist., V., p. 164. Type, *B. kjerulfi* Lapw.

Bryograptus ? multiramosus Gurley, sp. nov.

Polypary round-triangular in outline; length and breadth each 20^{mm}. Proximal extremity bearing a sicula 1^{mm} long. Branches numerous, dividing dichotomously, one being five times divided (including sicular division). Thecæ 30 to 35 in 25^{mm}, forming cylindrical tubes, free for one-half their length or a little less, pustuliferous. Virgula not seen.

Horizon and locality.—Several specimens on some pieces of Upper Cambrian shale from Matanné, Canada, sent by Sir J. William Dawson to the National Museum.

Dichograpsus Salter, 1863.

Quart. Jour. Geol. Soc. London, XIX., p. 139. Type, *D sedgwickii* Salter.

Dichograpsus remotus Gurley, sp. nov.

Only a single specimen seen. Branches very narrow, having a length of 25 to 35^{mm} between successive points of division, the latter apparently becom-

ing progressively more remote from one another. Thecæ not well shown, about 25 in 25^{mm}. The main characteristic of this species is the remoteness of the points of bifurcation and the small size of the branches.

Horizon and locality.—Calciferous shales (zone with *Dichograpsus flexilis*, etc.), Point Levis, Canada.

Dichograpsus abnormis (Hall).

Herrmann[1] regards this species as simply an "abnormal" specimen of *D. rigidus*. I am unable to agree with this view, the species apparently being well characterized.

Tetragrapsus Salter, 1863.

Quart. Jour. Geol. Soc. London, XIX., p. 140. Type *T. crucialis* Salter.

Tetragrapsus acanthonotus Gurley, sp. nov. Plate IV., Figs. 1, 1*a*.

Width of branches from apex of thecæ to virgula, 2.5–3^{mm}. Dorsal margins at intervals of from 1 to 3 thecæ (generally opposite every other theca) bearing spines 1^{mm} or less in length, which are integumentary processes, not connected with the virgula. Thecæ 17 to 20 in 25^{mm}, slightly curved with the upper lip produced into a rather acute denticle. Line of aperture concave, inclined (on distal side) to virgula about 120°.

Horizon and locality.—Calciferous shales about one and one-quarter miles N. N. W. of the East Railway Station, at Point Levis, Canada, opposite the iron foundry.

Recognizable at a glance by its spinose dorsal margin. The generic reference is made from a single small specimen seen.

Didymograpsus McCoy, 1851.

Brit. Palæozoic Fossils, p. 9.

Didymograpsus bipunctatus Gurley, sp. nov. Plate V., Figs. 7, 7*a*.

Sicula slender, short. Branches diverging from sicula at an angle of 110°, very slender, with an undulating dorsal margin, each undulation corresponding to a theca. Thecæ about 65 in 25^{mm}, curved, equally wide throughout, with the apertural margin straight, and retrotruncate. Between each pair of thecæ are two "pustules" (one at base of proximal theca, the other near its distal end), appearing as though joined by an elevated line. Owing to the close proximity of the series of elevated lines, the specimens, viewed in some directions, appear to possess a continuous undulating raised line.

Horizon and locality.—On a slab of Calciferous shale in a small collection from one mile N.W. of the East Railway Station, Point Levis, Canada. A dozen specimens, mostly small or immature, were seen.

[1] Nyt Mag. f. Naturvid, 1885, XXIX., p. 210.

From all species of the genus except two or three, this species is distinguished by its small size. From the remainder by the undulating dorsal margin and the double series of "pustules."

Didymograpsus perflexus Gurley sp. nov.

Branches diverging from a minute sicula at a variable angle, probably from 225° to 270°, variously directed subsequently from post mortem deflection, gradually widening from their origin to a maximum width of 3^{mm}. Maximum length observed (in a specimen whose width showed that it was situated far to the proximal side of other fragments, and that it could not have been near the sicula) 17^{cm}. Coenosarcal canal narrow, occupying not more than one-quarter or one-fifth of the extreme width of the branch. Thecæ 20 to 25 in 25^{mm}, almost or quite straight, very wide in proportion to their length, little wider (one-quarter or thereabouts) at aperture than at base; inclined to axis of branch about 30°; apertural margin straight, destitute of spines, obliquely directed,

Horizon and locality.—Upper Calciferous shales, Summit, Nev.

This species presents itself under very many aspects, so many in fact that I have several times suspected that two species were present. Subsequent study has, however, led to the conclusion that probably all these forms are to be referred to differences in preservation conditions, that is that they are preservation facies. To start with the angle of divergence varies within very wide limits, being at one extreme about two, and at the other about three right angles. Several intermediate positions are present. The true angle was probably nearer the upper than the lower limit, the lowering resulting from subsequent (post mortem) bending of the slender polypary. This seems not unreasonable especially when the inclination of the thecæ in some specimens is less than the average, and these same thecæ have every appearance of having been compressed backward against the virgula. Such pressure naturally tends to diminish the angle of divergence, measured as the latter is on the dorsal side. These two conditions (diminished angle and flattening of thecæ) were not, however, observed on the same specimen. The inclination of the thecæ to the virgula (measured of course, on the distal side), seems to increase slowly, those on the distal portion being somewhat more erect. They are also slightly more numerous in a given space. Upon each theca at the distal corner remote from the virgula, is a circular pustule-like body which may have been an orifice in the lateral wall.

This form probably approaches *D. nicholsoni* Lapw., and *D. suecicus* Tullb., more nearly than any others. The thecæ here are rather regularly 22 to 24 in 25^{mm} as opposed to 25 to 30 (average 26) in the same space, in Lapworth's species. Also *D. nicholsoni* differs in the somewhat rigid branch with a uniform width of about $1^{mm}.25$, and the concave thecal mouth usually prolonged into a denticle. With *D. suecicus* its affinities would seem even

closer, but in that species we have somewhat crooked thecæ, twice or one and one-half times as wide at mouth as at base, with the somewhat concave mouth often bearing a denticle.

Didymograpsus geminus (Hisinger).

(Miller's North American Geology and Palæontology, 1889, p. 186, Fig. 169.)

Concerning this form, it may be remarked (1) that Hisinger's *geminus* (*Lethaea Suecica*, Suppl. 2, 1840, p. 5, Part XXXVIII., Fig. 3) is a synonym for *D. murchisoni* Beck (Murchison's *Silurian System*, Part II., 1839, p. 694, Plate XXVI. Fig. 4); (2) that *D. murchisoni* is not known to be American (except as *var. furcillatus* Lapw.; see p. $\frac{1}{m}$); and (3) that the original of Miller's figure is Carruther's mal-identification (in Murchison's *Siluria*, 4 ed., 1867, Plate IV., Fig. 8) as *D. geminus* His., of *D. patulus* Hall.

Didymograpsus hirundo Salter, 1863.

Quar. Jour. Geol. Soc. London, XIX., p. 137, Fig. 13.

Graptolithus constrictus Hall, 1865, Can. Org. Rem., Dec. II., p. 76, Plate I., Figs. 23–27.

This species is very largely represented in collections from the main Point. Levis zone. The supposed constriction of the theca mentioned by Hall is clearly an illusion, due to the intervention of a thin film of shale which covers one theca along the furrow produced by the overlapping apertural margin of the next proximal theca. This produces an appearance as though the distal theca were interrupted and contracted to receive the next proximal one. Specimens in relief show the thecæ uncontracted.

Didymograpsus convexus Gurley, sp. nov. Plate V., Fig. 8.

Branches slender, in distal portion 1^{mm} wide, diverging from a small sicula with an upwardly concave-rounded curve, including between them (on the dorsal side, of course) an angle of about 265^{c}. Thecæ 20 to 22 in 25^{mm}, inclined to axis of branch 25° to 30°, widest at mouth, with a straight, apertural margin; the last making (on the distal side) an angle with the virgula of 105° to 110°; thecæ free for one-half their length.

Only two specimens were seen, but the aspect is such that they cannot be referred to *D. serratulus* or any other described species. Possibly it may be the proximal portion of *D. sagitticaulis*, but nearly fifty years have passed since the discovery of that species without the finding of any specimens long enough to connect the distal and proximal parts; hence the necessity for two names, at least pending the proof of such a connection which may be long delayed.

This species may be recognized by the broadly rounded curve at the base.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

Didymograptus sagitticaulis Gurley, sp. nov.

Graptolithus sagittarius (His.) Hall, Pal. N. Y., 1847, I., p. 272, t. 74, Fig. 1; "*Graptolithus sagittarius* Hall (non-His.)," etc., of subsequent writers; *Didymograptus sagittarius* Hall, Lapworth, 1886, Trans. Roy. Soc. Can., V., Sect. IV., pp. 180–181, 183–184.

This name is proposed to clear the synonymy. No name has ever been given to this species, that under which it has gone being derived merely from the erroneous identification of it with Hisinger's species. Very possibly the species is a distal fragment of one of the others in the same beds, but if so, it is so far distal that the chances of connecting it with the proximal portion are rather small, in the meantime it is important that it have a name in good standing, especially as, being a very common form, it occurs in nearly every list of species from the Lower *Dicellograpsus* zone, and usually appears under some clumsy explanatory circumlocution.

Horizon and locality.—Lower *Dicellograpsus* zone.

STEPHANOGRAPTUS GEINITZ, 1866.

Neues Jahrb. für Mineral., 1866, p. 124. Type, *S. gracilis* (Hall).

This generic name takes precedence of *Helicograptus* Nicholson,[1] and *Coenograptus* Hall,[2] both of which were founded upon the same species (*Graptolithus gracilis* Hall).

Stephanograptus crassicaulis Gurley, sp. nov.

Specimen resembling one-half of *S. gracilis* but with a much thicker main curved stem and branches, the former measuring from 0.50 to $0^{mm}.75$. in thickness, the latter in the distal portions attaining a width of 1^{mm}. The branches are given off from the main stem at first at a right angle, but with each succeeding branch the divergence becomes less. The thecæ on the distal portion of the branches measure 20 in 25^{mm}.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

This species differs from all other of the genus in its very stout polypary. Though only one-half of the polypary has been seen, the generic reference seems hardly open to doubt so much does the habit of the species resemble that of *S. gracilis*.

Stephanograptus exilis Lapworth, sp. nov.

Polypary bilaterally symmetric, consisting of two simple (or compound) monoprionidian branches about 40^{mm} long, diverging in opposite directions from the center of a minute radicular bar; branches bearing thecæ of type of those of *S. gracilis* Hall. Width of branches at origin about $0^{mm}.17$, proceding outward at first horizontally (180°), the deflection increasing, however,

[1] Ann. and Mag. Nat. Hist. 1868, II., p. 23.

[2] Twentieth Rep. N. Y. St. Cab. Nat Hist., 1868, p. 179.

at end of first theca to 240° ; branches continued in a gentle, flexuous curve to their extremities, averaging in width about $0^{mm}.5$. Thecæ 30 or 32 in 25^{mm} ; adnate to the coenosarcal canal, with straight or very slightly convex margins and slightly inclined apertural edge.

The affinities of this form are distinctly with *S. pertenuis* Lapworth and its associates, *S. explanatus* and *S. nitidulus*. From all these, however, it differs in absence of secondary branches and in general form of polypary.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N Y.

To the above description I may add that some specimens indicate that the primary branches give origin to secondary ones, probably from the athecaphorous margin.

AZYGOGRAPTUS NICHOLSON, 1875.

Ann. and Mag. Nat. Hist., XVI., p. 269. Type, *A. lapworthi* Nich.

Azygograptus? walcotti Lapworth, sp. nov.

Polypary unilateral, monoprionidian, consisting of a single flexuous and simple compressed branch proceeding almost horizontally from the side of an inconspicuous sicula, 50 to 75^{mm} in length, in average diameter about 0.5^{mm}. Thecæ 16 in 25^{mm}, without overlap, consisting of conical tubes, increasing slightly in diameter throughout, adnate to the coenosarcal canal, with straight or slightly convex ventral margins. Apertural margin a little inclined and projecting from the ventral margin for a distance equal to about one-half the diameter of the polypary and transgressing upon the periderm for a similar distance. Denticle almost rectangular; excavations and interspaces shallow and inconspicuous.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

This form has all the appearance of belonging to the curious genus *Azygograptus*. Two specimens occur in the collection. One lacks the proximal part; in the other there is evidence of the unilateral nature of the polypary and of the presence of the sicula. Further research may show that it belongs to the bilateral genus *Leptograptus*, but in any case it is a new and undescribed form of the family. If it actually belong to *Azygograptus*, this is the first specimen of the genus on the American side of the Atlantic, and there is special appropriateness in its dedication to Mr. Walcott, whose recent researches have done so much to elucidate the sequence and fossils of the strata in which it occurs.

LEPTOGRAPTUS LAPWORTH, 1873.

Geol. Mag. London, X, p. 558. Type, *L. flaccidus* (Hall).

Leptograptus ? macrotheca Gurley, sp. nov.

Known only in the form of a fragment of a branch. Thecæ long, curved, slender, finally becoming nearly perpendicular to the branch but slightly

inclined distalwards; apertural margin straight; proximal margin concave, not uniformly, but with a bluntly rounded angle. Thecæ 16–17 in 25^{mm}. Branch including thecæ 1^{mm} wide, of which the coenosarcal canal occupies about two-sevenths.

Horizon and locality.—Calciferous shales, Point Levis, Canada.

DICELLOGRAPSUS HOPKINSON, 1871.

Geol. Mag., VIII., p. 20. Type, *D. elegans* (Carruthers).

Dicellograpsus intortus[1] *polythecatus* Gurley, var nov.

A species occurs at Stockport which presents a close resemblance to Lapworth's species but shows some important differences, at least from his published description and figures. These differences are sufficient to justify its provisional varietal separation, although it is possible that they may be due to the structure being more perfectly shown by the Stockport specimens. It resembles Lapworth's species, in the mode of growth, character of thecæ and dimensions of the branches. Like that species the present form is also a Norman's Kill (= Glenkiln) form. The thecæ are uniformly 32 in 25^{mm}. The first six or eight bear spines almost as long as the thecæ. But the most important difference is that the mode of growth is exactly the same as that exemplified by *Dicranograptus furcatus* (Hall), that is to say, the thecæ are present alternately on the outer and inner margins of the branches, and the latter cross alternately over and under, showing a growth in opposite-turning spirals. Lapworth's figures indeed not only do not show this feature but on the contrary show the opposite condition. Nevertheless the conformity of type is so close that I suspect that this omission is an error, and that the British form, as well as the American, has the spiral mode of growth.

Where the proximal portion of the polypary is absent the appearance may resemble somewhat that of *Dicranograptus furcatus* (Hall) under similar conditions. The latter species has, however, much thicker branches (1^{mm} as against 0.6^{mm} for the present form), the thecæ are much coarser and are *all* provided with strong spines. The loops are also more elongate and narrow.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

Dicellograpsus gurleyi Lapworth, sp. nov.

Branches from 25^{mm} to 100^{mm} long, slender, gently concave distally; diverging immediately from sicula at an angle of 270°, which slowly decreases to a general angle of 240°; width at origin about 0.5^{mm}; maximum diameter 1.25^{mm} in adult parts of polypary. Thecæ averaging about 24 to 26 in 25^{mm}. without overlap, compressed proximally to form a deep excavation; ventral margin straight for first three-fourths of its length; convex in last fourth, Distal portion of theca of the rounded type found in the genus, isolated and

[1] *Dicellograpsus intortus* Lapworth, was described in Ann. and Mag. Nat. Hist. 1880, V., p. 161, Plate XIX., Figs. 19 a–c.

introverted, opening well within ventral margin of the polypary, the free portions occupying about one-fifth of entire length of theca. Excavation distinct, deeply curved, occupying about one-third of transverse diameter of polypary, the interspaces taking up less than one-fifth of the ventral margin.

This form certainly belongs to a group of Dicellograpsi comprising besides it three species as yet undescribed. All these forms agree in having thecæ of the same general type, with very short, isolated distal portion and small introversion; but they differ in size, length, and angle of divergence of the branches, and in the proportion of their thecæ. They are, however, all of the same geological age, and it is not outside the limits of possibility that they may be local representative forms of one and the same species.

The whole group is intimately related to the group typified by *D. forchhammeri* (Geinitz), into which it passes by almost insensible gradations.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

Dicellograpsus elegans (Carr).

Specimens occur in our Lower *Dicellograpsus* zone which agree in every respect with Carruther's species except that they show 24 to 28 thecæ in 25^{mm}, while Carruther's and also Lapworth's figures show but 20 to 22.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

DICRANOGRAPTUS HALL, 1865.

Can. Org. Rem., Dec. II., p. 112. Type, *D. ramosus* (Hall).

Besides *D. furcatus* two types of this genus occur in American strata, viz., *D. nicholsoni*, Hopk., with a very short proximal portion bearing very few thecæ (*ad plurimum* 8 or 9) and *D. ramosus* (Hall), with a much larger proximal portion bearing nearly twice as many thecæ (usually 15 or thereabouts).

Of *D. nicholsoni* 5 (perhaps ultimately reducible to 4) fairly well marked varieties occur which present a gradation from the non-spinose var. *arkansasensis* with an angle of 135° to 90° through *D. nicholsoni* (angle 80° to 70°) to the smaller angled spinose forms *whitianus* and *parvangulus* and finally to var. *diapason* with converging branches.

D. ramosus presents 2 varieties, the typical form with a stout polypary, occurring in the Lower *Dicellograpsus* zone and a much more slender variety occurring in the Upper *Dicellograpsus* zone at Magog.

Dicranograptus furcatus (Hall).

This species presents a very peculiar structure. In the compressed state it consists of several elliptic loops. The thecæ begin on the proximal, diprionidian portion, and are continued on the *outer* side of the *lower* half of the first loop. At the middle of the loop they become scalariform and on its *upper* half occupy the *inner* margin of the branch. Traced upward, on to the next loop, they are seen to be (owing to the recurving of the branch toward the median

line) again on the *outer* side, and the same phenomenon is repeated with each loop. Thus the thecæ are always on the *outer* margin on the *lower*, and on the *inner* margin on the *upper* half of each loop. Further between the two branches at their points of crossing a film of shale can frequently be seen, the branches lying in the shale at slightly different levels. Also the branches always cross alternately over and under. All this is easily and only explicable upon the supposition that the branches originally grew *spirally* upward, each describing an oppositely directed curve. Compression would then produce the successive ellipses with the thecæ directed alternately outward and inward. This mode of growth in a continual spiral seems, as far as I can judge from Lapworth's figures of the species, to be exhibited by his *Dicellograpsus caduceus* and *D. ziczac*.

Relative to its generic affinities it has been referred to both *Dicellograpsus* and to *Dicranograptus*. Having early noted the presence of the thecæ on the concavity of the first curve and the specimens not being the best, I thought it possibly a *Dicellograpsus* of the *caduceus* type, in which the first loop was closed. Better specimens, however, seem to show conclusively that the branches are united as in *Dicranograptus*. This portion is very short and like several other species it presents in this respect an approximation to *Dicellograpsus*.

Horizon and locality.—Lower *Dicellograpsus* zone (of which it is one of the most characteristic species) near Stockport, Columbia county, N. Y.

Dicranograptus nicholsoni Hopkinson.

Geol. Mag., VII., 1870, p. 357, Plate XVI., Fig. 3.

This species occurs in the Utica under a form which Professor Lapworth informs me does not differ from the typical.

Dicranograptus nicholsoni arkansasensis Gurley, 1892.

Dicranograptus arkansasensis, Ann. Rep. Geol. Surv. Ark., for 1890, III., pp. 416–7, Plate IX., Figs. 1, 2.

Proximal portion 9^{mm} long; branches diverging at an angle of 90° to 130°, curving upward at a short distance from their origin so as to include a smaller angle; thecæ 20 in the space of 25^{mm}; non-spinose.

Horizon and locality.—Lower *Dicellograpsus* zone, Arkansas.

Dicranograptus nicholsoni whitianus (Miller), 1883.

Graptolithus (*Climacograptus*) *ramulus* White (preoc.), 1874, Prelim. Rep. Invt. Fossils, p. 13; *ib.*, White, 1875, Rep. Wheeler Survey, IV., Part I., p. 62, Plate IV., Figs. 3*a–e*; *Graptolithus whitianus* Miller, 1883, Cat. Amer. Pal. Foss., 2d ed., p. 269; *Dicranograptus ramulus* Herrman, 1886, Nyt Mag. f. Naturvidensk., XXIX.

This form differs from the typical *D. nicholsoni* of the Utica in the smaller

angle (35° or 40° against 70° to 80° in the Utica specimens) and in the presence of short, rigid spines on the thecæ of the stem and on practically all those of the branches. In the latter features lies its chief difference from var. *parvangulus* Gurley. I should add that a careful examination of the type specimen shows the proximal portion to be longer than shown in White's figure, at least six thecæ being visible.

Dicranograptus nicholsoni parvangulus Gurley.

(*D. nicholsoni* Lapw., 1876, Armstrong, Young & Robertson's Cat. West. Scot. Foss., pp. 6–9, Plate III., Fig. 79; *ib.*, Lapw., 1877, Ann. Rep. and Proc. Belfast Nat. Field Club, I., p. 141, Plate VII., Fig. 2.)

Dicranograptus nicholsoni parvangulus Gurley, 1892.

Ann. Rep. Geol. Surv. Ark. for 1890, III., p. 417.

In the Stockport collection several examples of this variety occur which permit of the following description: Proximal portion about 6^{mm} long; at base 1^{mm}, and immediately below bifurcation 1.5^{mm} wide; with eight or nine thecæ, each with a short, sharp horizontal spine; branches 1^{mm} wide, diverging at an angle of 35° or 40° (or thereabouts), often bending very slightly towards one another immediately after the division, thus producing a slightly rounded, bulging appearance. Thecæ forming bent tubes, as in *D. nicholsoni* proper; as nearly as possible 24 in 25^{mm}; those on the proximal portion and the first few on the branches above the bifurcation spiniferous. On the branches not more than three spiniferous thecæ were seen.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y., and in Arkansas; Upper *Dicellograpsus* zone, Magog, Canada.

Professor Lapworth (letter, 1890) remarks the difference between this form and *D. nicholsoni*, saying that this, the Glenkiln (= Lower *Dicellograpsus* zone) form, has a smaller angle and spinose proximal thecæ. *D. nichclsoni* proper is not found below the Utica. This variety, on the contrary, ranges through both the Lower and the Upper *Dicellograpsus* zones but apparently not into the Utica.

Since publishing this variety, I have noticed its extremely close resemblance to *D. whitianus* Miller. Indeed the latter form appears to differ from the present one only in having all of the thecæ on the branches spinose. I might at this time unite the two forms were it not that var. *whitianus* rests upon a single specimen from a very far distant locality, and it is possible that further collections in Nevada may show the distinctive characters of *whitianus* to be sub-constant. Finally it may be noted that none of the eastern, or of the Arkansas specimens show any decided approximation to the condition found in *whitianus*.

Dicranograptus nicholsoni diapason Gurley, var. nov.

Proximal portion with three minute spines at base; measuring from base

to notch between branches five (sometimes as much as 6^{mm}), showing below the level of the notch, at most seven (usually six, sometimes five) thecæ ; width of proximal portion 1.25 to 1.50^{mm}; branches, in the compressed condition, 1 to 1.25^{mm} wide; diverging at an angle of 45° (sometimes slightly less) to 50°, with a very gentle inward curve which brings them into parallelism, or even approximates them still further. Thecæ forming bent tubes with the tip introverted, 24 or 25 in 25^{mm}; some of them (probably all on basal portion ; material here uncertain) bearing an acute spine.

This variety is a well-marked one. In form the most characteristic specimens approach closely *D. ziczac minimus* Lapw., but our form is at least twice as large as Lapworth's, and besides *D. ziczac* appears not to occur in our strata. From the characteristic calliper-shape as a basis, the variety shades into var. *parvangulus*, which has the branches straighter and continually divergent.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

CLIMACOGRAPTUS HALL, 1865.

Can. Org. Rem., Dec. 2, p. 3. Type *C. bicornis* (Hall).

Climacograptus antiquus Lapworth sp. nov.

(*Climacograptus antiquus*, Geol. Mag., 1873, X, p. 134, *nomen nudum; C. cælatus*, Lapworth, 1876, in Armstrong, Young & Robertson's Cat. West. Scot. Foss., p. 6, Plate I., Fig. 56; *ib.*, Lapworth, 1877, Ann. Rep. and Proc. Belfast Nat. Field Club, I, Part IV., p. 139, Plate VI., Fig. 39; *ib.* Lapworth, 1886, Trans. Roy. Soc. Can. for 1886, V. Sect. IV, p. 178. Synonymy *fide* Lapworth, letter.)

This being the first publication of the synonymy which establishes the species, it is to be regarded as a new one dating from this publication.

Climacograptus caudatus Lapworth,[1] 1876.

Climacograptus caudatus, in Armstrong, Young & Robertson's Cat. West. Scot. Foss., p. 6, Plate II., Fig. 48 ; *ib.*, Lapworth, 1880, Ann. and Mag. Nat. Hist., VI., p. 22.

Polypary attaining, in one proximally ("distally") incomplete specimen, a length (exclusive of prolonged virgula), of 80^{mm}. Maximum breadth, attained at proximal ("distal") extremity, 2.25^{mm}. Polypary increasing gradually in width, nearly the full width being attained by the middle of the polypary, so that the widening is less rapid from that point to the proximal ("distal") extremity, which latter is abruptly cut off. Distal ("proximal") extremity marked by extension of virgula. Lateral spines not seen (conditions of specimens unsatisfactory.) Virgula about 0.75^{mm} wide, prolonged

[1] For remarks on the present form and *C. caudatus laticaulis* see next page.

both proximally and distally for about 25^{mm} without very obvious decrease in size. Theca 16 to 20 in 25^{mm}, appearing to form bent tubes.

Horizon and locality.—Upper *Dicellograpsus* zone, Magog, Canada.

Climacograptus caudatus laticaulis Gurley, var. nov.

(*Climacograptus caudatus* Lapworth, 1877, Ann. Rep. and Proc. Belfast Nat. Field Club, I, Part IV., p. 138, Plate VI., Fig. 34.)

Polypary reaching a length of 60^{mm} or somewhat more; usually shorter; maximum width attained at extreme proximal ("distal") extremity, usually 3.5^{mm} or a little more. Outline of polypary obtriangular, continuously widening from the rather blunt, 1^{mm} wide distal ("proximal") extremity to the abruptly truncated proximal ("distal") extremity. Distal ("proximal") extremity marked by two rather small lateral spines and further by the prolonged virgula. Virgula strap-like, prolonged both proximally and distally at least 25^{mm} without any evidence of termination. In the distal ("proximal") direction, the diminution in size in the distance mentioned is apparent, while in the proximal ("distal") direction, it is very slight. The broad strap-like virgula forms a conspicuous ridge-like elevation along the median line, of one lateral face, appearing less distinct on the other. Thecæ 22–26 in 25^{mm}, apparently with the outer wall concave-indented below, and rectangular above. Excavation indenting polypary for about one-third of its width, not at right angles but inclined (on distal side, of course) about 75° to virgula. Young individuals (with a length much less than maximum for the species) have, nevertheless, attained nearly the maximum width.

Horizon and locality.—Upper *Dicellograpsus* zone, Magog, Canada.

I at first had a great deal of trouble with the preceding two forms. The first light on the subject was obtained by noticing that to my two forms corresponded respectively the two figured at different times by Lapworth under the name of *Climacograptus caudatus*. That they are at least varietally distinct there is no doubt. For Lapworth's *caudatus* of 1876 (which of course remains the *caudatus*) is about $2^{mm}.75$ (possibly 3^{mm} *ad maximu*) wide, has only 18 thecæ in 25^{mm}, and a more attenuated polypary which enlarges much more slowly; while the *caudatus* of 1877 (var. *laticaulis*) is 3^{mm} wide (probably, judging from my specimens, *ad minimum*), and has 24–26 thecæ and a more widely obtriangular polypary. Further in var. *laticaulis* the virgula is very stout and strap-like, recalling that of *Diplograpsis foliaceus*. Correlated with these differences in theca-numbers and polypary width, is the different proportions of the "denticles." In *caudatus* rhombic, with the ventral and apertural margins about equal, in var. *laticaulis* they are considerably wider than long. It is possible that the forms are entirely distinct, but the material consisting merely of flattened films is not satisfactory on this point.

Climacograptus oligotheca Gurley, sp. nov.

Polypary acutely isosceles-triangular, long and slender, widening very slowly; distal ("proximal") extremity bearing two short lateral spines. Virgula stout, occupying about one-sixth width of polypary, greatly prolonged proximally and distally, the distal ("proximal") extension sometimes consisting merely of a short triangular process, sometimes of a virgular extension terminating in a vesicular dilatation, but generally forming a straight broadly filiform process which may be traced for some distance without evidence of termination. No vesicle or "disk" visible at end of proximal ("distal") prolongation. Length, 11^{cm} or less; width about 2^{mm}. Ventral margins straight, interrupted by notches corresponding to the thecal mouths. Thecæ 12 to 14 in 25^{mm}.

Horizon and locality.—Upper *Dicellograpsus* zone, Magog, Canada.

This species is readily recognized by the proximal and distal extension of the virgula, and by its straight parallel sides incised by a series of straight notches at comparatively distant intervals. It is most closely allied to *C. antiquus*, but is usually longer and has but 12 to 14 thecæ in 25^{mm}, while *C. antiquus* has (by measurement on Lapworth's figure) 20 in the same space.

Climacograptus caelatus Lapworth, 1875.

Quart. Jour. Geol. Soc. London, XXXI., p. 655, Plate XXXV., Fig. 8; *not ib.*, Lapworth, 1876 (see *C. antiquus*).

The principal interest in our specimens attaches to the "disk" which forms the proximal ("distal") termination of the virgula. This body is an obtriangulat-cordate leaflet, bilaterally symmetrical, and traversed medianly by the virgula. Some appearances suggest that it may possibly consist of two superposed elliptic leaflets. It is sometimes at a distance from, sometimes close to, or in actual contact with the proximal ("distal") end of the polypary. From the (apparent) dilatations of the virgula seen in *D. vesiculosus* Nich., *D. palmeus* (Barr.), and *D. trifidus* Gurley, it differs markedly in its distinct bilateral symmetry, and flat leaf-like appearance. This "disk" is present in a large proportion of the specimens.

Horizon and locality.—Upper Calciferous, Summit, Nevada. Identified by Professor Lapworth from specimens sent him.

Climacograptus kamptotheca Gurley, sp. nov.

Polypary pretty uniformly $1^{mm}.5$ broad and 35 to 40^{mm} long; distally ("proximally") tapering gradually for about length of last 7 or 8 thecæ to the narrow rounded extremity; maintaining its full width to the proximal ("distal") extremity which is abruptly truncated. Virgula straight or slightly zigzagged, prolonged distally ("proximally") as a straight needle-like process, 2 or 3^{mm} long; and proximally ("distally") as a filiform extension which in one specimen extends 12^{mm} without terminating in any "disk."

Thecæ cylindrical, at first directed perpendicularly outward from virgula, then deflected through nearly 90° so as to become directed proximally ("distally") and almost parallel with virgula, and at the same time to make a small angle with the plane of the shale-section (rising up from or sinking down into the rock); pretty uniformly 24 to 26 in 25^{mm}; apparently without any overlap.

Horizon and locality.—Upper *Dicellograpsus* zone, Magog, Canada.

Easily recognized, in connection with the dimensions, by the superficial outline which shows a series of rather squarish thecal outlines distinctly alternating on the two sides.

Climacograptus phyllophorus Gurley, sp. nov. Plate IV., Figs. 4–6.

(*Climacograptus parvus* Hall, 1865, Can. Org. Rem., Dec. 2, p. 57; *nomen nudum.*)

Polypary gradually widening from distal ("proximal") extremity, attaining its full width in the length of 6 to 8 thecæ; ventral margins above this point parallel. Length, exclusive of proximally ("distally") prolonged virgula, 10 to 30^{mm} (usually about 20^{mm}); maximum width, $1^{mm}.5$ to 2^{mm}; distal ("proximal") extremity narrow and abrupt, with two short lateral spines; and an extension of virgula for 2 to 6^{mm}. Proximal ("distal") extremity abrupt, showing a prolongation of the virgula which terminates in a "disk," varying in shape (apparently with age) from narrowly lanceolate to broadly elliptic, 6 to 10^{mm} long, and 1 to 3^{mm} broad. Thecæ 30 to 36 in 25^{mm}, short, perpendicular, apertural margins concave, the excavation nearly horizontal (slightly inclined distalward), occupying nearly one-third of width of the polypary.

Horizon and locality.—Lower *Dicellograpsus* zone (of which it is one of the most characteristic species), Stockport, N. Y.

This species was identified by a comparison with Hall's types in the American Museum of Natural History in New York City. It is very distinct from *C. bicornis* and *C. typicalis*, differing from the former in the absence of the three prominent spines and the disk developed around them, and from the latter by the constantly prolonged virgula.[1] It is also much smaller than either *bicornis* or *typicalis*. The species which it most closely resembles is *C. scalaris* (L. = *normalis* Lapworth), and for this form it has been mistaken (as it easily might be, and formerly was by me) by Ami.

The chief interest in the species lies in the "disk." This has the form of and strikingly resembles an elliptic pinnate-veined leaflet, a resemblance heightened by the likeness of the virgula to the midrib, and the presence of several obscure, obliquely directed fibers running from it on either side out-

[1] If, as would naturally be expected, *C. typicalis* has a proximally ("distally"(extended virgula, it never (within my experience) shows it on the shale, and for practical diagnosis this absence is all-sufficient.

wards and proximalwards. An exactly similar but differently-shaped appendage is constant in *C. caelatus* from Nevada, and probably it is equally constant in *C. phyllophorus*, though here the longer, more slender virgula is more frequently broken. This appendage appears to differ from that found in such species as *Diplograpsis vesiculosus* Nich., in being accurately bilaterally symmetrical, and in being plainly traversed by and not forming (as apparently is the case in *D. vesiculosus*) a dilatation of the virgula.

Diplograpsis McCoy, 1850.

Ann. and Mag. Nat. Hist., VI., pp. 270–2. Type. *D. pristis* Hisinger.

Diplograpsis stenosus Gurley, sp. nov.

Polypary long and very slender, when complete probably measuring in the majority of cases about 50^{mm} or somewhat more; breadth 1 to 1.5^{mm}, the latter figure being rarely exceeded. Polypary very gradually widening from near its distal ("proximal") end. Sicula and extreme distal ("proximal") end of polypary unknown. Virgula usually obscure, frequently invisible, apparently not distally prolonged. Thecæ about 20 in 25^{mm}, straight, free for one-half of their length, inclined to virgula 25° to 30°; apertural margin probably perpendicular to virgula.

Horizon and locality.—Upper *Dicellograpsus* zone, Magog, Canada.

No other species of the genus possesses a polypary so slender in proportion to its length. In this respect (only in this, however) it approaches most nearly some Upper Silurian species, notably *D. tamariscus* Nich., and *D. longissimus* Kurck.

Glossograpsus Emmons, 1856.

American Geology, I., Part II., p. 108. Type *G. ciliatus* Emmons.

Glossograpsus arthracanthus Gurley, sp. nov.

(*Diplograpsus ciliatus* Emmons, 1856, Am. Geol., I., Part II., pp. 105–106, Plate I., Fig. 19.)

"Straight, thin and ciliated; ciliæ, bulbous and jointed or transversely marked, proceeding from the point of each serration; serrations unequal, the intervening smaller serrations rounded, the larger prolonged and run into the base of the ciliæ, axis distinct.

"The specimen is imperfect, but probably, from the character of the column, it was free. The entire width of the column embracing the extended lateral ciliæ is one-fourth of an inch, the membrane is rather less than one-eighth of an inch wide, the margins appear to be dissimilar. In another specimen the end is rounded and complete, and furnished like the sides with ciliæ. Found in Augusta county, Virginia."

This form is apparently a *Glossograpsus*. The name *ciliatus* having been previously used (by Emmons, and in the same paper) for a *Glossograpsus*, the name *arthracanthus* is proposed for this form to clear synonymy. The dupli-

cation of the "serrations" is probably due to a slightly oblique pressure causing the lower latero-ventral margin of the polypary to extend beyond the upper latero-ventral margin of the same, in such a manner that the corners of the thecal mouths alternate. I have seen this condition in *G. ciliatus* and several other graptolite species.

LOMATOCERAS BRONN, 1834.

Lomatoceras, Lethæa Geognostica, I., pp. 55–56; *Monoprion* Barrande, 1850, Grapt. de Bohême, p. 14; *Monograpsus* Geinitz, 1852, Die Graptolithen, p. 32; *Monograptus* of later writers; *Lagenograptus* Hall, 1870, 20th Rep. N. Y. St. Cab. Nat. Hist., 2 ed., p. 261. Type *L. priodon* Bronn.

There can be no question as to the clear priority of this name, though it has been asserted, reasserted and taken for granted that it was preoccupied.[1] I find no evidence of such preoccupation, at least I have searched with the aid of several entomological friends for the name as a genus of insects without success. Bronn says that his genus is "non *Lomatocera*, insectorum genus." This is not preoccupation and there is no reason why both names should not stand. Finally if for any reason *Lomatoceras* cannot stand, *Monograpsus* must still give place to Barrande's *Monoprion*, as Geinitz's alteration of the last to *Monograpsus* (to harmonize with his substitution of *Diplograpsus* for *Diprion*) preoccupied, cannot be accepted.

GLADIOLITE BARRANDE, 1850.

Grapt. de Bohême, p. 68. Syn. *Retiolites*, *ibid.*, p. 68, footnote. Type *G. geinitzianus*.

Barrande proposed *Gladiolites* as the name of the genus; merely adding that *Retiolites* could be used if *Gladiolites* were considered too near *Gladiolus*. By no rule of nomenclature can *Retiolites* have any standing (except as an unnecessary synonym). Accepted usage must therefore be rejected and *Gladiolites* restored.

Gladiolites venosus (Hall).

Pal. N. Y., 1852, II., p. 40, Plate XVII*a*, Figs. 2*a-c*.

The figure of this species given by Spencer[2] and copied from him by Miller,[3] bear no very evident resemblance to Hall's species. Moreover, after a careful examination of a fine specimen (unquestionably co-specific with Spencer's species) from the Niagara beds at Hamilton, Ontario (whence Spencer's species came), has convinced me that the reference of it to *G. venosus* (Hall), is incorrect. Whatever else it may be it is not Hall's form,

[1] Beck in Murchison's Silurian System, 1839, Part II., p. 696; Bronn, 1849, Geschichte der Natur, p. 667; Geinitz, 1852, Die Graptolithen, p. 18.

[2] Bull. Mus. Univ. State Mo., 1884, I., p. 16, Plate I., Fig. 2.

[3] North Amer. Geol. & Pal., p. 202, Fig. 214.

as, besides other reasons, it lacks any very evident graptolitic texture or structure and has 24–26 oblique ribs as compared with (from measurements on Hall's figures) some 35–40 for *G. venosus*.

RETEOGRAPTUS HALL, 1859.

Pal. N. Y., III., p. 518. Type *R. tentaculatus* (Hall).

A specimen of *R. tentaculatus* in the American Museum of Natural History, New York City, exhibits practically the same type of structure as is seen in *R. geinitzianus* from the Lower *Dicellograpsus* zone. I have no doubt that they are congeneric. Lapworth has, however, referred *R. geinitzianus* to his *Clathrograptus*[1] (founded on *C. cuneiformis* Lapw.). If *C. cuneiformis* be, indeed, congeneric with *R. geinitzianus*, the genus *Clathrograptus* must be suppressed.

Reteograptus geinitzianus Hall, 1859.

Reteograptus geinitzianus, Pal. N. Y., III., p. 518, with fig.; *Reteograptus barrandi* Hall, 1860, 13th Rep. N. Y. St. Cab. Nat. Hist., pp. 61–62, with fig.; *Clathrograptus geinitzianus* Lapworth, 1880, Ann. and Mag. Nat. Hist., V., p. 22.

Some particularly favorable preservation-conditions occur among the Stockport specimens. They permit the following description: The polypary in this species is parallel-sided blunt-fusiform, and consists of skeleton and periderm. The skeleton shows, at and imbedded in its base a body apparently a sicula, flanked on either side by a spine which is directed obliquely upward. Two virgulas are present, each zigzagged in the basal expanding portion of the polypary, straight in the middle (parallel-sided) portion, and (?) again zigzagged in the upper contracting part. From the convex angles of the zigzagged, and at intervals from the straight portion of the virgula, a parietal ledge[2] runs in each lateral wall to the ventral margin, where it undergoes an abrupt deflection downward to the parietal ledge of the theca next below, to which it appears to connect just before (*i. e.*, at a point on the lateral surface just within the ventral margin) that ledge reaches its point of downward deflection. At the latter point a mouth ledge connects the parietal ledge with its fellow on the opposite side. These three chitinous threads (the horizontal limb of the parietal ledge, the vertical limb of the same and the mouth ledge), all meet at the point of deflection with rounded edges, and together form the rim of the mouth opening, which is thus somewhat squarish or slightly trapezoidal. I have seen nothing corresponding to the inner cross-ledges and the material furnishes no data for an opinion *pro* or *con* as to the existence of any interthecal partition planes.

[1] Geol. Mag., 1873, X., p. 559.

[2] I here follow the nomenclature of Holm (Bihang til kongl. Sv. Vet.-Akad. Handl., 1890, XVI., No. 7).

The periderm consists of three, rarely only two,[1] longitudinal series of meshes of a subrhomboidal shape which alternate in adjacent rows, and give off from the middle points of the meshes of the outer rows (the rows along the ventral margin) short, stout spines which are the mouth ledges crushed V-shape. The relation of the three rows of peridermal meshes to the skeleton is not known. The parietal ledges form the upper and lower borders of the meshes, and are deflected inwards (*i. e.*, into the intra-polyparial space) to their virgular connection at the inner borders of the outer rows of meshes (?). The meshes are covered by a membrane which is markedly thinner in the center of the mesh.

The structure is therefore in substantial agreement with that observed by Holm in *Retiolites* and *Stomatograptus*, the latter of which, *Reteograptus*, seems particularly to resemble.

DICTYONEMA HALL, 1851.

Am. Jour. Sci., XI., p. 401. Type *D. retiforme* (Hall).

Like Mr. Holm[2] I think the taxonomic condition in this genus very unsatisfactory. While there seems no possibility of denying to *D. flabelliforme* the possession of a true sicula, certain other species are certainly non-siculate. The extraordinary vertical range is also, as Mr. Holm remarks, good reason for suspicion of the generic references. When I first studied *Desmograptus macrodictyon*, I thought Mr. Hopkinson's genus was a first step in the establishment of a natural series of cleavage planes in the genus, especially as both species occur at equivalent horizons. But on subsequently studying *D. devonicus* I found that on no characters now predicated of *Desmograptus* could this species be denied admission to it. So that we only have two wide-ranging genera instead of one such genus. Another explanation (one which has been suggested before, and one which, though I at first could not favor, I incline now to think not impossible) is that the characters (form, dimensions of mesh, thickness, etc. of branches) on which (being dependent on conditions of fossilization) we have to rely are really of very subordinate biologic value. And as Mr. Holm says there is no chance of a rational subdivision until we know more of the basal end.

Dictyonema, *cf. neenah* Hall.

Rep. Progr. Supt. Geol. Surv. Wisc., 1861, p. 7.

A single specimen, perhaps, referable to this species is found in the collection. It shows a considerable portion of the network, but not the proximal

[1] Several specimens show two series below and three above, the interpolated middle series being wedge-shaped (*i. e.*, narrower and less perfectly developed) below. The specimens showing the periderm are *much* larger than those showing the skeleton, and though plainly congeneric, may not be cospecific.

[2] Bih. t. k. Svensk. Akad. Handl., 1890, XVI., Afd. IV., No. 7.

extremity. The two layers of the flattened funnel-shaped polypary are pressed almost into contact, which circumstance, together with the slightly slicken-sided condition of the specimen, renders its accurate specific description difficult. Enough, however, can be made out to state that, as flattened, the polypary is flabellate, 40^{mm} in length, and the same in breath, of a triangular shape, with the distal side of the triangle rounded. The branches of the polypary are subparallel, very gradually diverging, about 1.5^{mm} apart, forking into two branches several times in their course towards the periphery.

Horizon and locality.—Upper *Dicellograpsus* zone, Magog, Canada.

I have compared this form with the other species of the genus, and especially with those forms which approach it in vertical distribution. Only two species have heretofore been described from approximately the same horizon, viz., *D. moffatense* Lapw., and *D. neenah* Hall. With the former of these the present form needs no comparison. The latter species was described from the Trenton limestone of Wisconsin.

Dictyonema perexile Gurley, sp. nov.

Dictyonema delicatulum Dawson, 1883, Can. Nat. and Quart. Jour. Sci. X., pp. 461–3; "D. n. sp. (=*D. delicatulum* Dawson, preoccupied)" Ami, 1889, Ann. Rep. Geol. Surv. Can. for 1887, p. 117 K.).

Proposed to replace Dawson's *delicatulum*, that name having been previously used by Lapworth (Quart. Jour. Geol. Soc., London, 1881, XXXVII., p. 172.).

Dictyonema actinotum Gurley, sp. nov.

Dictyonema hamiltoniæ Hall, 1865, Can. Org. Rem., Dec. 2, p. 58; *nomen nudum*.

Specimens seen very incomplete. Branches radiating rapidly, bifurcating mostly near the base (in correspondence with their rapid radiation) rather conspicuously longitudinal-striate, 0.5–0.6^{mm} wide, 25–30 in 25^{mm}. Dissepiments rather stout, wiry, apt to be curved, transverse or slightly oblique. Meshes subquadrangular or with rounded angles. Thecæ present but indistinct. Length of mesh uncertain, perhaps 2–2.5^{mm}.

Horizon and locality.—Devonian (Hamilton formation), Kashong Creek, Cayuga county, New York. Several specimens badly preserved, but apparently of this species, occur in the Hamilton at Moscow, N. Y.

Dictyonema blairi Gurley, sp. nov.

Proximal end of polypary unknown. Branches radiating slowly, subparallel, usually scarcely but nearly 0.4^{mm}, occasionally 0.5^{mm}, *ad max.*, and arranged transversely about 20–25 in 25^{mm}. Interspaces generally about one and one-half times as wide as branches or slightly more. Dissepiments rather slender, about 0.25^{mm}, thick *ad max.* Sometimes straight. Usually more or less

oblique. Meshes correspondingly variable in shape, from quadrangular to triangular. The shortest are about 1.25^{mm} long, and the greatest length in unbroken meshes (*i. e.*, where all the dissepiments are entire) is probably near 3^{mm}. Texture Carbonaceous. Branches rather obscurely striate, dividing at an acute, rather sharp, angle.

Resembles somewhat *D. gracile* Hall, but the branches are a little more slender and the interspaces a little wider, and especially the number of branches transversely in this species is less (20–25 as against 25–30 in *D. gracile*). I am indebted to Mr. Charles Schuchert for having drawn my attention to this species.

Horizon and locality.—Lower Carboniferous (Choteau limestone), Sedalia, Mo. Collected by and dedicated to Mr. R. A. Blair, of Sedalia.

DESMOGRAPTUS HOPKINSON, 1875.

Quar. Jour. Geol. Soc., London, XXXI., p. 668. Type, *D. cancellatum* Hopk.

Desmograptus macrodictyum Gurley, sp. nov.

Polypary subparallel, rather abruptly widening from a non-siculate, fibrous, root-like base; branches thick, almost straight, longitudinally striate, bifurcating quite regularly; bifurcations evenly rounded, the dividing branches curving into parallelism and coalescing prior to redivision. Thecal mouths pressed against the stem, appearing as rounded or transversely oval elevations, about 36 in 25^{mm}. Meshes very long in proportion to their width, formed only by the coalescence of the branches, true dissepiments being entirely absent.

Horizon and locality.—Calciferous shales, Point Levis, Canada.

This species differs decidely from all species of *Dictyonema* except *D. cancellatum* Hopk., for which its author proposed (as a subgenus) *Desmograptus*, saying:

"The most distinctive characteristic is that the meshes or interspaces are chiefly formed by the branches coalescing and dividing by virtue of their curvilinear direction, being connected by transverse filaments only here and there where not sufficiently undulated to be brought quite into contact, and not being connected at all where the undulations do not bring the branches into tolerably close proximity to each other."

In the species here described no dissepiments are anywhere visible, the division of branches appearing to take place mostly at regular intervals, a series of divisions extending across the whole width of the polypary at the same level. I regard *Desmograptus* as entitled to full generic rank if, as I think, *D macrodictyum* belongs to it.

From all species it is distinguished by the entire absence of dissepiments; from *D. cancellatum* in particular by the straight branches, the greatly elongated meshes and the generally stouter structure.

Desmograptus devonicus Gurley, sp. nov.

(*Dictyonema cadens* Hall, 1865, Can. Org. Rem., Dec. 2, p. 58; *nomen nudum*).

Polypary very irregular in its mode of growth; scarcely a true dissepiment present. Branches dividing and re-fusing irregularly, leaving round-elliptic or round-quadrangular (the prevailing type) meshes. The irregularity renders an accurate count of the branches difficult, but there seem to be about 12–15 in 25^{mm}. The thickness varies considerably, though most of the branches measure 1^{mm}, or nearly that. Longitudinally, there are about six or seven meshes in 25^{mm}.

Horizon and locality.—Devonian (Hamilton formation), Moscow, N. Y.

DENDROGRAPTUS HALL, 1862.

Rep. Geol, Surv., Wisc., I., p. 21. Type, *D. hallianus* (Prout).

Dendrograptus unilateralis Gurley, sp. nov.

Portion of polypary seen, 35^{mm} in length, by 12^{mm} in breadth. Branches in the single specimen seen, diverging mostly (entirely?) to one side, whence results a one-sided appearance; varying in thickness from 0.25^{mm} to 0.50^{mm}, mostly approaching the latter size; given off at rather distant intervals, at a variable angle (roughly approximating 60°), very soon curving toward or into parallelism with the parent stem. Thecæ unknown.

The specimen consists of a slightly weathered, flattened film. Obscure indications of thecæ were seen, but they were too obscure to permit of detailed description.

Horizon and locality.—Upper *Dicellograpsus* zone, Magog, Canada.

Dendrograptus arundinaceus (Hall), 1847.[1]

Graptolithus arundinaceus, Pal. N. Y., I., Plate LXXIV. Fig. 8.

No description of this species has been published. Hall's figure gives as much information as would a description of the same specimen, which, of course, is a mere fragment. I was able, however, to make out the distinctness from it of the Dendrograpti subsequently published.

Horizon and locality.—The type specimen (the only one) in the American Museum of Natural History, New York City, was collected from the Utica shale, at Turin, Lewis county, N. Y.

Dendograptus, *cf. serpens* Hopkinson.

Quart. Jour. Geol. Soc., London, XXXI., 1875, p. 665, Plate XXXVII., Fig. 3

A single specimen referable to this genus in the Summit, Nevada, collection seems most nearly related to Hopkinson's species. It consists of an

[1] Overlooked entirely by cataloguers, which is not surprising considering its entire absence from both text and index.

exceedingly tangled maze of branches, most of which are of extreme tenuity, and cross and recross one another in inextricable confusion. A few larger branches are seen curving around and among the smaller. No thecæ were observed, although certain indistinct crenulations may represent these structures. Sicula and terminations, both proximal and distal, unknown.

Horizon and locality.—Upper Calciferous, Summit, Nevada.

CARYOCARIS SALTER, 1863.

Quart. Jour. Geol. Soc., London, XIX., p. 139. Type, *C. wrightii.*

This genus, referred by its author to the Crustacea, was defined as follows:

"A long pod-shaped, bivalved carapace (with distinct hinge-pits), rounded anteriorly, subtruncate behind, and with the back and front subparallel. The surface is smooth, or with only oblique wrinkles near the margins, but with no parallel lines of structure. Body? Telson and appendages?

"All I know of this pretty little Crustacean, an inch long and rather more than a third of an inch wide, is contained in the above note. I was fortunate enough to find the tubercles (Huxley found them also in *Ceratiocaris*), which I suppose indicate teeth, and corresponding pits at each end of a short hinge-fulcrum.

"The shelly carapace is solid for its size; it appears to have a good deal of lime in its composition. The genus is evidently distinct, though so little is known of the entire form.

"Everywhere in the Skiddaw Slate district. I have named it after Mr. Bryce M. Wright."

It may be re-defined as follows: Polypary bilaterally symmetrical; proximal portion possibly thecaphorous; distal portion consisting of one (two?) median and two lateral appendages. Lateral appendages symmetrically disposed with reference to median line of polypary, apparently inserted on proximal portion through the medium of an elliptic body ("tubercles" of Salter); median appendage bilaterally symmetrical overlying superposed adjacent margins of lateral appendages. Texture yellowish-translucent, gauzy, resembling the wings of insects.

The above description is based upon American specimens of the type species, the other species being known only in the form of the lateral appendages. The substance of the polypary does not differ much from that of the Diplograpses in the same beds. In texture it resembles *Dawsonia* more nearly than any other genus, and the resemblance is increased by the presence of a marginal filament. At present, however, there is nothing to show that *Dawsonia* actually represents the lateral appendages of species of this genus, and the relationship of the two genera may be summed up as follows: The Dawsonias are certainly comparable, as regards texture and general appear-

ance to the lateral appendages found in *Caryocaris*, but to them only. Had these structures stood alone without evidence of further organization, I should probably have referred them to *Dawsonia*. But although a majority of these appendages are found isolated, in *C. oblongus* all of the few specimens obtained, and in the other two species, a not inconsiderable number of specimens are found paired in such a way as to leave no doubt that this is their normal condition, and their separation a result of decomposition. Further in several (of course very exceptional, but evidently so only as being exceptionally favorable preservation-conditions) specimens of *C. wrightii* I have seen these symmetrically paired lateral appendages attached to the distal end of a single median proximal portion on which I believed thecæ could perhaps be traced. It seems very doubtful indeed whether the future will show similar organization in any species at present referred to *Dawsonia*.

It is needless to add (as Professor Lapworth points out) that this is not, as Salter supposed, a Crustacean, but from its resemblance to *Dawsonia* appears to be a graptolite.

Caryocaris wrightii Salter, 1863. Plate V., Figs. 1, 2.

Quart. Jour. Geol. Soc., London, XIX., p. 139, Fig. 15.

Polypary, consisting of a proximal portion, two lateral and one (two?) median appendages. Proximal portion acutely triangular, 9^{mm} long, 3^{mm} wide *ad max.* (at insertion of lateral appendages). Condition of thecæ uncertain. Lateral appendages round-triangular, obliquely truncated superiorly by the superior margin, 7^{mm} long, 2.5 to 3^{mm} wide *ad max.* (at point of divergence of adjacent margins), apex proximally directed, apparently inserted upon the proximal portion through the medium of the "tubercle" which lies just within the outer margin; outer margin almost straight, bordered by a single filament which is interrupted by openings which appear to be continued into the substance of the appendage; superior margin slightly convex, running downward and inward, finally overlapping (or underlapping) the corresponding margin of the opposite appendage, furnished with a row of cîlia-like processes; inferior margins curving downward and outward around the "tubercle" to join the outer margin at the proximal extremity. Median appendage somewhat shorter than lateral, the superposed adjacent margins of which it overlies) acutely isosceles-triangular, symmetrical with reference to median line of polypary, the equal sides almost straight, the apex projecting in the notch left by the diverging superior margins of the lateral appendages.

Horizon and locality.—Upper Calciferous, Summit, Nevada.

The specimens occur only as flattened films, a condition unfavorable for the determination of structure. The symmetrical disposition of the lateral appendages would seem to imply a similar symmetrical structure in the

proximal portion of the polypary. Possibly a second median appendage may underlie (as the first overlies) the notch left by the diverging adjacent margins of the lateral appendages.

This species is much less common than *C. curvilatus*. I have not as yet seen it in the Point Levis shales. The lateral appendages differ from those of *C. curvilatus* in their smaller size, triangular shape and in the single marginal filament, interrupted at intervals.

Caryocaris oblongus Gurley, sp. nov. Plate IV., Fig. 2.

Species known only in the form of the lateral appendages. These are roundish-oblong, about 15^{mm} long and about 3^{mm} wide, showing near the proximal part a discolored spot which probably represents the "tubercle." Appendages superposed as in the other species of the genus. Substance thinner, presenting no evidence of structure. Filaments absent. No trace of median appendages.

Horizon and locality.—Calciferous shales, Point Levis, Canada.

This species is distinguished from the other two by its regularly oblong shape. There is no evidence that it represents a developmental stage of *C. curvilatus*.

Caryocarus curvilatus Gurley, sp. nov. Plate IV., Fig. 3; Plate V., Fig. 3.

Species known only in the form of the lateral appendages. These are broadly elliptic in outline, 20 to 30^{mm} long; 10^{mm} wide, more or less; with one margin convex, bordered by half a dozen horse-hair-like filaments which run parallel converging toward the ends, enclosing a ribbon-like space which is obscurely transverse-striate (merely transverse-wrinkled ?); superior margin with two acute processes between which extends a row of cîlia-like processes; outer margin bordered by a single filament.

Horizon and locality.—Upper Calciferous, Summit, Nevada; Calciferous, Point Levis, Canada.

This species presents very perplexing varieties of facies from differences in the amount and direction of pressure, and perhaps differences of age. Thus the width may be only one-third the natural, greatly altering the appearance of the species. But most difficult to decipher are the complicated foldings and refoldings of the marginal filaments; usually, however, these retain their parallelism. This latter fact implies that they were united by a thin membrane. The frequent foldings, however, show that they were either free except at one end, or (more probably, perhaps) that the uniting material was so thin as to offer no resistance to flexion.

Although the number of specimens are very numerous (forming more than one-half of the whole number of graptolite specimens from Nevada), I have not seen one specimen possessing the proximal portion. Several have,

however, been seen with the appendages overlapping, both in the Nevada and in the Point Levis specimens.

The lateral appendages of this species differ from those of *C. wrightii* and *C. oblongus* in their much larger size, usually more rotund shape, and in the multiple marginal filaments.

DAWSONIA NICHOLSON, 1873.

Ann. and Mag. Nat. Hist., XI., p. 139. Type, *D. acuminata* Nich.

Dawsonia monodon Gurley, sp. nov. Plate V., Fig. 4.

Polypary somewhat rhomboidal in outline; 10 to 14^{mm} long, 3 to 5^{mm} wide *ad max.;* apex drawn out to a tapering mucro; dentate margin gently curving from apex to the blunter extremity, interrupted at junction of upper with middle third by a small acute tooth; non-dentate border obtusely isosceles-triangular joined near its lower end by a groove that has run close beside and parallel to it; proximal extremity rounded.

Horizon and locality.—Calciferous shales, Point Levis, Canada.

Easily recognizable by the single tooth and its (for the genus) large size.

Dawsonia tridens Gurley, sp. nov. Plate V., Fig. 5.

Polypary elliptic in outline, 3 to 4^{mm} long and 1 to $1^{mm}.5$ wide, with the sharper extremity drawn out to a point; one margin bearing three acute teeth whose upper borders curve inwards, indenting the polypary and terminating in a "pustule"; opposite margin smooth, joined at a very acute angle, near its lower end, by a groove which has run downward close beside and parallel to the margin. The blunt extremity rounded, grooved for a short distance. Substance corneous, thin. The denticles can be seen to extend into the polypary whenever a thin film of shale separates the adjacent margins of successive teeth, and seem to indicate thecæ, but from the extreme tenuity of the film it is not possible to determine this point definitely.

Horizon and locality.—Calciferous shales, Point Levis, Canada.

This species is marked off from all other by the tridentate margin. In outline and size it resembles most closely *D. acuminata* Nich.

THAMNOGRAPTUS HALL, 1859.

Pal. N. Y., III., p. 519. Type, *T. typus* Hall.

Thamnograptus barrandii Hall.

Rastrites barrandii[1] Hall, Pal. N. Y., III,, 1859, pp. 520–521, with Fig.; *Thamnograptus barrandii* Lapworth, 1886, Tran. Roy. Soc. Can. for 1886, V., Sec. IV., p. 178.

This is certainly, as Lapworth says, a *Thamnograptus*. A single specimen shows, scalariform-wise, the thecal mouth-openings. They occupy about

[1] The name *Rastrites barrandii* was preoccupied by Harkness (Quart. Jour. Geol.

two-thirds the width of the stem and are in the proportion of 25 to 25^{mm}. The aspect of the stem seems to oppose the view that the thecæ project as in other genera form a coenosarcal canal. They appear rather to have been excavated out of the substance of the branch.

PHYCOGRAPTUS GURLEY, gen. nov.[1]

Polypary consisting of long, slender, flexuous stems, apparently simple, with an entire border and many-segmented contents. Each segment with a single, central pit, seemingly the mouth of a cell, the latter apparently excavated in the substance of the stem. Sicula and virgula unknown. When preserved the substance is carbonaceous. Type *P. brachymera*.

This genus forms one of a group the relation of which to the more typical graptolites is at present somewhat dubious. They are all of a carbonaceous texture and some in addition show pits, apparently the mouth-openings of a cell of some kind, but there is at present no evidence that such cell is of the theca type found in the more typical graptolites.

Phycograptus brachymera Gurley sp. nov. Plate V., Fig. 6.

Greatest length observed, 175^{mm}; width, 1^{mm}; number of segment in 25^{mm}, about 18; each segment as long as, or little longer than wide (rarely one and one-half times as long); pit large.

Horizon and locality.—Lower *Dicellograpsus* zone, Stockport, N. Y.

Phycograptus laevis (Hall).

Graptolithus laevis Hall, 1847, Pal. N. Y., I., p. 274, Plate LXXIV., Fig. 7; probably not *ib.* Süss, 1851, Haidinger's Wissensch. Abhandl., IV., p. 114, Plate IX., Fig. 6.

A careful examination of the type specimen shows that it is about 55^{mm} long,[2] uniformly about 0^{mm}.8 wide throughout. In one place a break occurs which, in the light of the other species, I incline to interpret as a segmentation, especially as the adjacent ends appear smoothly cut. Obscure traces of a median virgula-like chitinous thread are visible at intervals; no pits could be made out with certainty. The specimen is a mere film much wrinkled.

In another specimen I was able, however, to make out distinctly all the essential *Phycograptus* characters, viz., segmentation, pits, marginal grooves; and, in addition, what appeared to be traces of a central chitinous virgula-like thread.

Horizon and locality.—Utica shale, Turin, Lewis County, N. Y. Two specimens in American Museum of Natural History.

Soc., London, 1855, XI., p. 475). As, however, the species has already been referred to, and is not preoccupied in *Thamnograptus*, there is no reason why it should not stand.

[1] φυκος, sea weed; γραφω, I write.

[2] "Specimen uncovered after the figure made" (note on label).

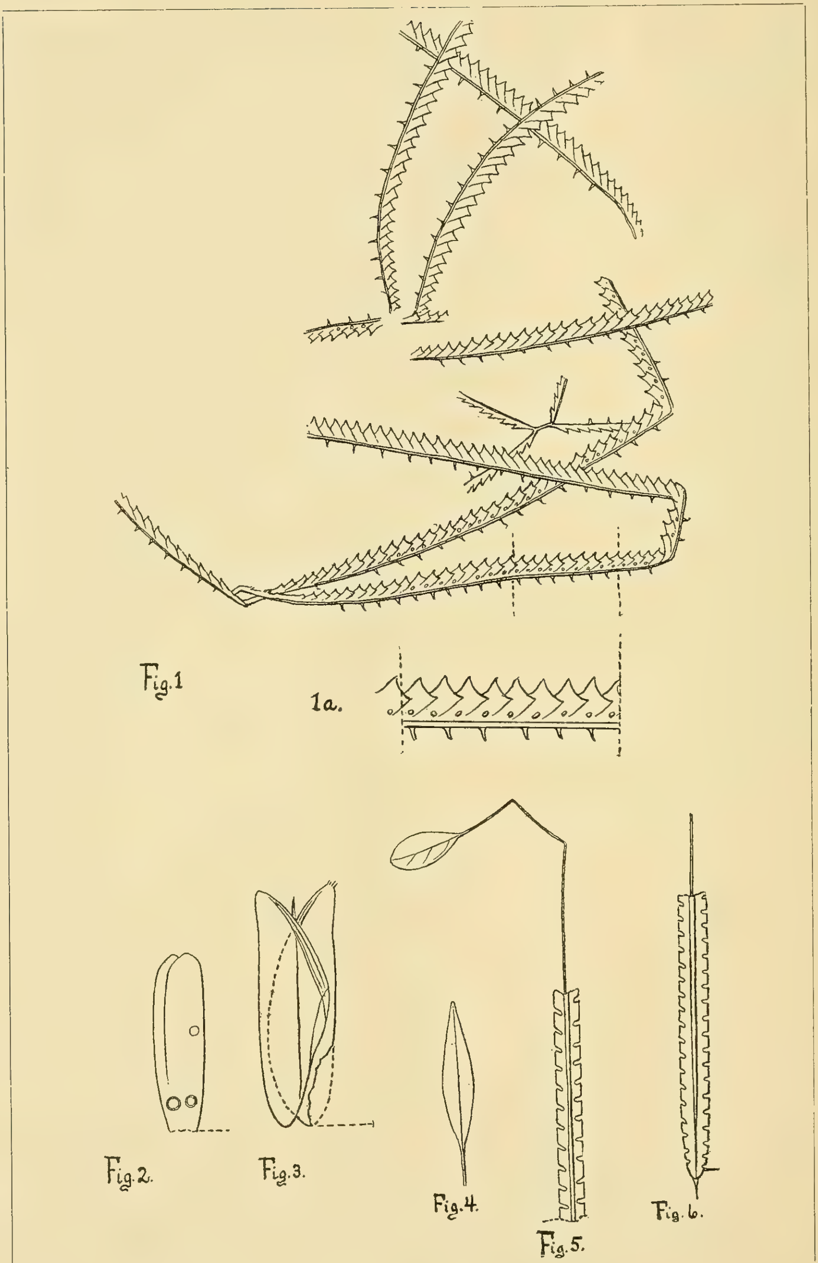
Fig.1
1a.
Fig.2.
Fig.3.
Fig.4.
Fig.5.
Fig.6.

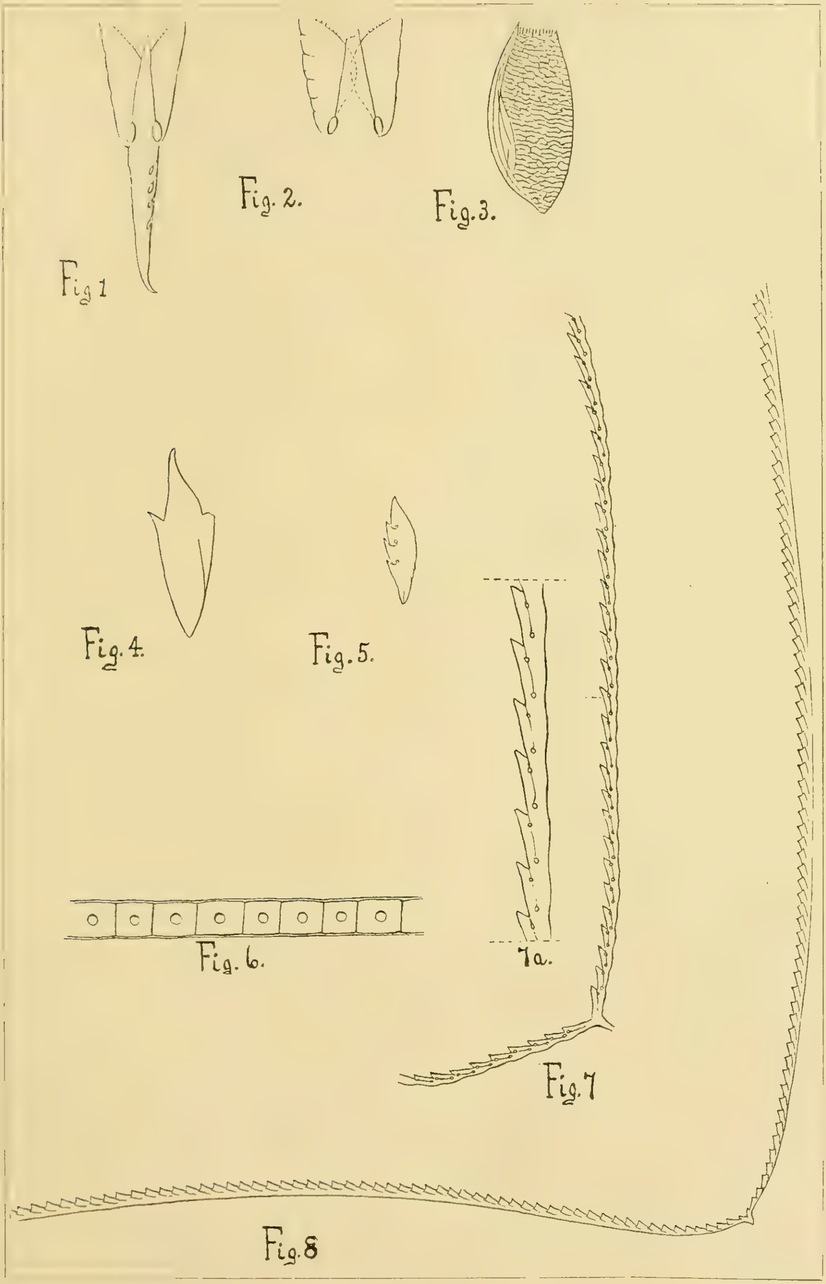
Fig 1
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
7a.
Fig. 7
Fig. 8

DESCRIPTION OF FIGURES.

PLATE IV.

FIG. 1.—*Tetragrapsus acanthonotus;* nat. size, and (1*a*) × 2.

FIG. 2.—*Caryocaris oblongus*, × 2. Showing conjoined lateral appendages.

FIG. 3.—*Caryocaris curvilatus*, × 2. Showing conjoined lateral appendages.

FIG. 4.—Proximal "disk" of *Climacograptus phyllophorus;* narrow form, × 2.

FIG. 5.—*Climacograptus phyllophorus*, × 2. Showing "disk," and distal extension from it of the virgula terminating in the "polypary."

FIG. 6.—*Climacograptus phyllophorus*, × 2.

PLATE V.

FIG. 1.—*Caryocaris wrightii* Salter, × 2. Showing proximal portion, one median and two lateral appendages,

FIG. 2.—*Caryocaris wrightii*, × 2. Showing the lateral appendages, with the interrupted external, and the ciliated superior borders.

FIG. 3.—*Caryocaris curvilatus*, nat. size. Showing the outline, marginal filaments and ciliated superior border.

FIG. 4.—*Dawsonia monodon*, × $\frac{3}{2}$.

FIG. 5.—*Dawsonia tridens*, × 3. Showing the dentated border.

FIG. 6.—*Phycograptus brachymera*, × 6.

FIG. 7.—*Didymograpsus bipunctatus*, × 3. Fig. 7*a*, enlargement of thecæ, × 6.

FIG. 8.—*Didymograpsus convexus*, × $\frac{3}{2}$.

LIST OF GRAPTOLITES KNOWN FROM AMERICAN STRATA.

After some thought, I have concluded that I cannot do better than to connect this list with that given in our standard catalogue (Miller's North American Geology and Palæontology; and Supplement) as a base line. For this purpose the two lists (Miller's and mine) are given in parallel columns. Italicized genera and species are new additions to Miller's list, most of them, of course, being subsequent publications.

Acanthograptus Spencer, 1878.	Acanthograpsus Spencer, 1878.
granti Spencer, 1878.	granti Spencer, 1878.
pulcher Spencer, 1884.	pulcher Spencer, 1884.
	Amphigraptus Lapworth, 1873.[1]
	Type A. divergens.
	divergens (Hall), 1859.
	Azygograptus Nicholson, 1875.
	? *walcotti* Lapworth, sp. nov.
	Bryograptus Lapworth, 1880.
	lentus Matthew, 1895.

	[*Bryograptus* Lapworth—*cont'd.*]
	multiramosus Gurley, sp. nov.
	patens Matthew, 1893.[6]
	spinosus (Matthew), 1893.[17]
Bythograptus Hall, 1861.	Buthograptus Hall, 1861.
laxus Hall, 1861.	laxus Hall, 1861.
Callograptus Hall, 1865.	Callograptus Hall, 1865.
elegans Hall, 1865.	elegans Hall, 1865.
granti Spencer, 1884.	granti Spencer, 1884.
minutus Spencer, 1884,	minutus Spencer, 1884.
multicaulis Spencer, 1884.	multicaulis Spencer, 1884.
niagarensis Spencer, 1878.	niagarensis Spencer, 1878.
salteri Hall, 1865.	salteri Hall, 1865.
Calyptograptus Spencer, 1878.	Calyptograpsus Spencer, 1878.
cyathiformis Spencer, 1878.	cyathiformis Spencer, 1878.
[Omitted entirely.]	*micronematodes* Spencer, 1884.
[Omitted entirely.]	*radiatus* Spencer, 1884.
subretiformis Spencer, 1878.	subretiformis Spencer, 1884.
	Caryocaris Salter, 1863.
	curvilatus Gurley, sp. nov.
	oblongus Gurley, sp. nov.
	wrightii Salter, 1863.
Cladograpsus Geinitz, 1852.	[Never properly defined; should be dropped.]
dissimilaris Emmons, 1856.	Dicranograptus dissimilaris.
inequalis Emmons, 1856.	Dicranograptus ? inequalis.
	Clathrograptus Lapworth, 1873.
	cuneiformis Lapworth, 1873.
	Clematograptus Hopkinson, 1875,[2] Type C. multifasciatus.
	multifasciatus (Hall), 1859.
Climacograptus Hall, 1865.	Climacograptus Hall, 1865.
antennarius Hall, 1863–5.	Cryptograptus antennarius.
	antiquus Lapworth, sp. nov.
bicornis Hall, 1847.	bicornis (Hall), 1847.
	peltifer Lapworth, 1876.[3]
	tridentatus Lapworth, 1876.[3]
	caelatus Lapworth, 1875.
	caudatus Lapworth, 1876.
	laticaulis Gurley, var. nov.
	confertus Lapworth, 1875.
emmonsi Walcott, 1886.	? ? emmonsi Walcott, 1886.

[Climacograptus Hall—*cont'd.*]	[Climacograptus Hall—*cont'd.*]
	oligotheca Gurley, sp. nov.
parvus Hall, 1865 [not defined].	*phyllophorus* Gurley, sp. nov.
	scharenbergi Lapworth, 1876.[3]
typicalis Hall, 1865.	typicalis Hall, 1865.
	wilsoni Lapworth, 1876.[3]
Clonograptus Hall, 1873.	Dichograpsus Salter, 1863.
flexilis Hall, 1858.	Dichograpsus flexilis.
rigidus Hall. 1858.	Dichograpsus rigidus.
	Corynoides Nicholson, 1867.[4] Type C. calicularis.
	calicularis Nicholson, 1867.[4]
	Cryptograptus Lapworth, 1880.[5] Type C. tricornis (=marcidus Hall).
	antennarius (Hall), 1865.
	tricornis (Carruthers), 1858.[5]
Coenograptus Hall, 1868. Type C. divergens.	Stephanograptus Geinitz, 1866. Type S. gracilis.
divergens Hall, 1859.	Amphigraptus divergens.
gracilis Hall, 1847.	Stephanograptus gracilis.
surcularis Hall, 1868.	Stephanograptus surcularis.
Cyclograptus Spencer, 1884.	Cyclograptus Spencer, 1884.
rotadentatus Spencer, 1884.	rotadentatus, Spencer, 1884.
Dawsonia Nicholson, 1873.	Dawsonia Nicholson, 1873.
acuminata Nicholson, 1873.	acuminata Nicholson, 1873.
campanulata Nicholson, 1873.	campanulata Nicholson, 1873.
	monodon Gurley, sp. nov.
rotunda Nicholson, 1873.	rotunda Nicholson, 1873.
tenuistriata Nicholson, 1873.	tenuistriata Nicholson, 1873.
	tridens Gurley, sp. nov.
Dendrograptus Hall, 1865.	Dendrograptus Hall, 1862.
[Omitted entirely.]	*arundinaceus* (Hall), 1847.[6]
compactus Walcott, 1879.	compactus Walcott, 1879.
dawsoni Spencer, 1884.	dawsoni Spencer, 1884.
diffusus Hall, 1865.	diffusus Hall, 1865.
divergens Hall, 1865,	divergens Hall, 1865.
dubius Miller, sp. nov.	dubius Miller, 1889.
erectus Hall, 1865.	erectus Hall, 1865.
flexuosus Hall, 1865.	flexuosus Hall, 1865.
frondosus Spencer, 1884.	frondosus Spencer, 1884.
fruticosus Hall, 1865.	fruticosus Hall, 1865.
gracilis Hall, 1865.	gracilis Hall, 1865.

[Dendrograptus Hall—*cont'd.*]	[Dendrograptus Hall—*cont'd.*]
gracillimus Lesquereux, 1877.	gracillimus (Lesquereux), 1878.
hallanus Prout, 1851.	hallianus (Prout), 1851.
novellus Hall, 1879.	novellus Hall, 1879.
prægracilis Spencer, 1884.	prægracilis Spencer, 1884.
? primordialis Matthew, 1885.	? primordialis Matthew, 1885.
ramosus Spencer, 1884.	ramosus Spencer, 1884.
	cf. *serpens* Hopkinson, 1875.[2]
simplex Walcott, 1879.	simplex Walcott, 1879.
spinosus Spencer, 1884.	spinosus Spencer, 1884.
striatus Hall, 1865.	striatus Hall, 1865.
tenuiramosus Walcott, 1979.	tenuiramosus Walcott, 1879.
	Desmograptus Hopkinson, 1875.
	devonicus Gurley, sp. nov.
	macrodictyon Gurley, sp. nov.
	Dicellograpsus Hopkinson, 1871.[7]
	anceps (Nicholson), 1867.[4]
	caduceus Lapworth, 1876.[3]
	divaricatus (Hall), 1859.
	elegans (Carruthers), 1867.[8]
	gurleyi Lapworth, sp. nov.
	intortus Lapworth, 1880.[5]
	polythecatus Gurley, sp. nov
	moffatensis (Carruthers), 1858.[9]
	rigidus Lapworth, 1880.[5]
	sextans (Hall), 1847.
Dichograptus (syn. for Graptolithus).	*Dichograpsus* Salter, 1863. Good genus.
	abnormis (Hall), 1858.
	flexilis (Hall), 1858.
	logani (Hall), 1858.
	? milesi (Hall), 1861.
	octobrachiatus (Hall), 1858.
	octonarius (Hall), 1858.
	proximatus Matthew, 1895.
	ramulus (Hall), 1865.
	remotus Gurley, sp. nov.
	rigidus (Hall), 1858.
Dicranograptus Hall, 1865.	Dicranograptus Hall, 1865.
	clingani Carruthers, 1868.[10]
	dissimilaris (Emmons), 1856.
divaricatus Hall, 1859.	Dicellograpsus divaricatus.

[Dicranogtaptus Hall—*cont'd.*]	[Dicranograptus Hall—*cont'd.*]
furcatus Hall, 1847.	furcatus (Hall), 1847.
	? inequalis (Emmons), 1856.
	nicholsoni Hopkinson, 1870.
	arkansasensis Gurley, 1892.
	diapason Gurley, var. nov.
	parvangulus Gurley, 1892.
	whitianus Miller, 1883.
ramosus Hall, 1847.	ramosus Hall, 1847.
	rectus Hopkinson, 1872.[19]
sextans Hall, 1847.	Dicellograpsus sextans.
Dictyonema Hall, 1852.	Dictyonema Hall, 1852.
	actinotum Gurley, sp. nov.
	blairi Gurley, sp. nov,
expansum Spencer, 1884.	expansum Spencer, 1884.
fenestratum Hall, 1851.	fenestratum Hall, 1851.
	flabelliforme (Eichwald), 1840.[11]
gracile Hall, 1852.	gracile Hall, 1852.
grande Nicholson, 1873.	grande Nicholson, 1873,
	cf. *homfrayi* Hopkinson, 1875.[2]
irregulare Hall, 1865.	irregulare Hall, 1865.
murrayi Hall, 1865.	murrayi Hall, 1865.
neenah Hall, 1861.	neenah Hall, 1861.
	perexile Gurley, sp. nov.
pergracile Hall & Whitfield, '72.	pergracile Hall & Whitfield, '72.
pertenue Foerste, 1887.	pertenue Foerste, 1887.
quadrangulare Hall, 1865.	quadrangulare Hall, 1865.
retiforme Hall, 1843.	retiforme (Hall), 1843.
robustum Hall, 1865.	robustum Hall, 1865.
scalariforme Foerste, 1887.	scalariforme Foerste, 1887.
splendens Billings, 1874.	splendens Billings, 1874.
tenellum Spencer, 1878.	tenellum Spencer, 1878.
websteri Dawson, 1860.	websteri Dawson, 1860.
Didymograptus M'Coy, 1851.	Didymograpsus M'Coy, 1851.
	arcuatus (Hall), 1865.
	bifidus (Hall), 1858.
	bipunctatus Gurley, sp. nov.
caduceus Salter, 1853.	caduceus (Salter), 1853.
	convexus Gurley, sp. nov.
	euodus Lapworth, 1875.[2]
	extensus (Hall), 1858.
	extenuatus (Hall), 1865.

[Didymograptus M'Coy—*cont'd.*]	[Didymograpsus M'Coy—*cont'd.*]
geminus Hisinger, 1840.	Not American (see p. 1/m).
	hirundo Salter, 1863.
	indentus (Hall), 1858.
	murchisoni furcillatus Lapworth, 1875.[2]
	nitidus (Hall), 1858.
	patulus (Hall), 1858.
	perflexus Gurley, sp. nov.
	serratulus (Hall), 1847.
	similis (Hall), 1865.
	cf. *superstes* Lapworth, 1876.[3]
Diplograptus M'Coy, 1854.	Diplograpsis M'Coy, 1851.
amplexicaulis Hall, 1847.	D. foliaceus.
angustifolius Hall, 1859.	angustifolius (Hall), 1859.
ciliatus Emmons, 1856.	Glossograpsus arthracanthus.
	dentatus (Brongniart), 1828.[16]
dissimilaris Emmons, 1856.	D. foliaceus.
	dubius Spencer, 1884.
	euglyphus Lapworth, 1880.[5]
foliaceous (?) Murchison, 1839.	foliaceus (Murchison), 1839.
	(=amplexicaule Hall, 1847.)
	(=dissimilaris Emmons, 1856.)
	(=laciniatus Emmons, 1856.)
	(=obliquis Emmons, 1856.)
	(=pristis Hall, 1847.)
	(=rugosus Emmons, 1856.)
	(=simplex Emmons, 1844.)
foliosus Emmons, 1856.	? foliosus Emmons, 1856.
folium Hisinger, 1837.	Not American (see p. 1/m).
hudsonicus Nicholson, 1875,	hudsonicus Nicholson, 1875.
hypniformis White, 1874.	hypniformis White, 1874.
inutilis, Hall 1865.	inutilis (Hall), 1865.
laciniatus Emmons, 1856.	D. foliaceus.
marcidus Hall, 1859.	Cryptograptus tricornis.
mucronatus Hall, 1847,	Lasiograptus mucronatus.
obliquus Emmons, 1856.	D. foliaceus.
peosta Hall, 1861.	peosta (Hall), 1861.
pristiniformis Hall, 1858.	D. dentatus.
pristis (?) Hisinger, 1837.	D. foliaceus.
putillus Hall, 1865.	putillus (Hall), 1865.

[Diplograptus M'Coy—*cont'd.*]	[Diplograpsis M'Coy—*cont'd.*]
	quadrimucronatus (Hall), 1865.
rugosus Emmons, 1856.	D. foliaceus.
rectangularis McCoy, 1851.	Climacograptus rectangularis.
secalinus Hall, 1847.	secalinus (Hall), 1847.
simplex Emmons, 1844.	D. foliaceus.
spinulosus Hall, 1859.	Glossograpsus spinulosus.
	trifidus Gurley, 1892.
	truncatus Lapworth, 1876.[3]
whitfieldi Hall, 1859.	whitfieldi (Hall), 1859.
Glossograptus Emmons, 1856.	Glossograpsus Emmons, 1856.
	arthracanthus Gurley, sp. nov.
ciliatus Emmons, 1856.	ciliatus Emmons, 1856.
setaceus Emmons, 1856.	setaceus Emmons, 1856.
	spinulosus (Hall), 1859.
	Goniograptus M'Coy, 1877. Type G thureaui.
	thureaui selwyni Ami, 1889.
Graptolithus Linnæus, 1736.	Established upon inorganic objects; should be dropped entirely.
abnormis Hall, 1858.	Dichograpsus abnormis.
alatus Hall, 1858.	Tetragrapsus alatus.
annectans Walcott, 1879.	Leptograptus annectans.
approximatus Nicholson, 1873.	Tetragrapsus approximatus.
arcuatus Hall, 1865,	Didymograpsus arcuatus.
bifidus Hall, 1858.	Didymograpsus bifidus.
bigsbyi Hall, 1865.	Tetragrapsus bigsbyi.
bryonoides Hall, 1858.	Tetragrapsus serra.
clintonensis Hall, 1843.	Lomatoceras clintonense.
constrictus Hall, 1865.	Didymograpsus hirundo.
crucifer Hall, 1858,	Tetragrapsus crucifer.
dentatus Emmons, 1842.	Diplograpsis foliaceus.
denticulatus Hall, 1858.	Tetragrapsus denticulatus.
divergens Hall, 1859.	Amphigraptus divergens.
extensus Hall, 1858.	Didymograpsus extensus.
extenuatus Hall, 1865.	Didymograpsus extenuatus.
flaccidus Hall, 1865.	Leptograptus flaccidus.
fruticosus Hall, 1858.	Tetragrapsus fruticosus.
gracilis Hall, 1847.	Stephanograptus gracilis.
headi Hall, 1858.	Tetragrapsus headi.
indentus Hall, 1858.	Didymograpsus indentus.
laevis Hall, 1847.	Phycograptus lævis.

[Graptolithus Linnæus—*cont'd.*]	[Should be dropped entirely.]
logani Hall, 1858.	Dichograpsus logani.
milesi Hall, 1861.	Dichograpsus milesi.
multifasciatus Hall, 1859.	Clematograptus multifaciatus.
nitidus Hall, 1858.	Didymograpsus nitidus.
octobrachiatus Hall, 1858.	Dichograpsus octobrachiatus.
octonarius Hall, 1858.	Dichograpsus octonarius.
patulus Hall, 1858.	Didymograpsus patulus.
pennatulus Hall, 1865.	Didymograpsus pennatulus.
quadribrachiatus Hall, 1858.	Tetragrapsus quadribrachiatus.
quadrimucronatus Hall, 1865.	Diplograpsis quadrimucronatus.
ramulus Hall, 1865.	Dichograpsus ramulus.
richardsoni Hall, 1865.	Holograptus ? richardsoni.
sagittarius (Linnæus) Hall, 1847.	Didymograpsus sagitticaulis.
scalaris (Linnæus) Hall, 1847.	A thoroughly bad species.[20]
serratulus Hall, 1847,	Didymograpsus serratulus.
similis Hall, 1865.	Didymograpsus similis.
subtenuis Hall, 1877.	Leptograptus subtenuis.
whitianus Miller, 1883.	Dicranograptus nicholsoni whitianus.
	Holograptus Holm, 1881.[12] Type A. expansum.
	? richardsoni (Hall), 1865.
Inocaulis Hall, 1852.	Inocaulis Hall, 1851.[13]
anastomotica Ringueberg, 1888.	anastomotica Ringueberg, 1888.
arbuscula Ulrich, 1879.	arbuscula Ulrich, 1879.
bellus Hall and Whitfield, 1875.	bellus Hall and Whitfield, 1875.
cervicornis Spencer, 1884.	cervicornis Spencer, 1884.
diffusus Spencer, 1884.	diffusus Spencer, 1884.
divaricatus Hall, 1879.	divaricatus Hall, 1879.
phycoides Spencer, 1884.	phycoides Spencer, 1884.
plumulosus Hall, 1851.	plumulosus Hall, 185–.
problematicus Spencer, 1878.	? problematicus Spencer, 1878.
ramulosus Spencer, 1884.	ramulosus Spencer, 1884.
walkeri Spencer, 1884.	walkeri Spencer, 1884.
	Lasiograptus Lapworth, 1873.[1] Type L. costatus Lapw.
	bimucronatus (Nicholson), 1869.[13]
	mucronatus (Hall), 1847.
	Leptograptus Lapworth, 1873.[1]
	annectans (Walcott), 1879.
	flaccidus (Hall), 1865.
	subtenuis (Hall), 1877.

Loganograptus Hall, 1868. Type L. headi.[14]	Dichograpsus Salter, 1863.
alatus Hall, 1858.	Tetragrapsus alatus.
crucifer Hall, 18—.	Tetragrapsus crucifer.
headi Hall, 18—.	Tetragrapsus headi.
logani Hall, 18—.	Dichograpsus logani.
octobrachiatus Hall, 18—.	Dichograpsus octobrachiatus.
	Lomatoceras Bronn, 1834.
	clintonense (Hall), 1843.
	convolutum coppingeri (Etheridge), 1878.
Megalograptus Miller, 1874.	Megalograptus Miller, 1874.
welchi Miller, 1874.	welchi Miller, 1874.
Monograptus Emmons, 1856.	(=Monograpsus Geinitz,—a synonym for Lomatoceras.)
convolutus coppingeri Etheridge, 1878.	Lomatoceras convolutum coppingeri.
elegans Emmons, 1856.	Didymograpsus ? elegans.
rectus Emmons, 1856.	Didymograpsus ? elegans.
Nemagraptus Emmons, 1856.	Nemagrapsus Emmons, 1856.
capillaris Emmons, 1856.	capilaris Emmons, 1856.
elegans Emmons, 1856.	Stephanograptus gracilis.
	Phycograptus Gurley, gen. nov.
	brachymera Gurley, sp. nov.
	lævis (Hall), 1847.
Phyllograptus Hall, 1858.	Phyllograptus Hall, 1858.
angustifolius Hall, 1858.	angustifolius Hall, 1858.
anna Hall, 1865.	anna Hall, 1865.
	? *cambrensis* Walcott, sp. nov.
dubius Spencer, 1884.	Diplograpsis dubius.
ilicifolius Hall, 1858.	ilicifolius Hall, 1858.
loringi White, 1874.	loringi White, 1874.
typus Hall, 1858.	typus Hall, 1858.
Protograptus Matthew, 1885.	Protograptus Matthew, 1885.
alatus Matthew, 1885.	alatus Matthew, 1885.
	Protovirgularia M'Coy, 1851.[15] Type P. dichotoma.
	dichotoma ? M'Coy, 1851.[15]
Ptilograptus Hall, 1865.	Ptilograptus Hall, 1865.
foliaceus Spencer, 1878.	foliaceus Spencer, 1878.
geinitzianus Hall, 1865.	geinitzianus Hall, 1865.
plumosus Hall, 1865.	plumosus Hall, 1865.

Rastrites Barrande, 1850.	Not American.
barrandi Hall, 1856.	Thamnograptus barrandi.
Retiograptus Hall, 1865.	Reteograptus Hall, 1859.
barrandi Hall, 1860.	Reteograptus geinitzianus.
eucharis Hall, 1865.	eucharis Hall, 1865.
genitzianus Hall, 1859.	geinitzianus Hall, 1859.
tentaculatus Hall, 1858.	tentaculatus (Hall), 1858.
Retiolites Barrande, 1850.	*Gladiolites* Barrande, 1850.
ensiformis Hall, 1858.	Trigonograpsus ensiformis.
venosus Hall, 1852.	venosus (Hall), 1852.
Rhizograptus Spencer, 1878.	Rhizograpsus Spencer, 1878.
bulbosus Spencer, 1878.	bulbosus Spencer, 1878.
Straurograptus Emmons, 1856.	Staurograpsus Emmons, 1856.
dichotomus Emmons, 1856.	dichotomus Emmons, 1856.
	Stephanograptus Geinitz, 1866.
	crassicaulis Gurley, sp. nov.
	exilis Lapworth, sp. nov.
	gracilis (Hall), 1847.
	surcularis (Hall), 1868.
Tetragraptus Salter, 1863.	*Tetragrapsus* Salter, 1863. A good genus. Type *T. crucialis* Salter 1863.
"This genus is not regarded with much favor. Graptolithus bryonoides is made the typical species."	*acanthonotus* Gurley, sp. nov.
	alatus (Hall), 1858.
	approximatus Nicholson, 1873.
	bigsbyi (Hall), 1863.
	crucifer (Hall), 1858.
	denticulatus (Hall), 1858.
	fruticosus (Hall), 1858.
	headi (Hall), 1858.
	hicksi Hopkinson, 1875.[2]
	quadribrachiatus (Hall), 1858.
	serra (Brongniart), 1828.[16]
Thamnograptus Hall, 1859.	Thamnograptus Hall, 1859.
anna Hall, 1865.	anna Hall, 1865.
	barrandi (Hall), 1859.
bartonensis Spencer, 1878.	bartonensis Spencer, 1878.
capillaris Hall, 1859.	capillaris Hall, 1859.
multiformis Spencer, 1884.	? multiformis Spencer, 1884.
typus Hall, 1859.	typus Hall, 1859.
	Trigonograpsus Nicholson, 1869.[13] Type T. ensiformis.
	ensiformis (Hall), 1858.

NOTES TO LIST.

References are here given to the articles in which will be found the original description of such newly introduced foreign genera and species as are not elsewhere (in connection with the tables or descriptions of species) properly cited.

[1] Geol. Mag., London, 1873, X., pp. 500–4, 555–60.

[2] Hopkinson & Lapworth, Quart. Jour. Geol. Soc., London, 1875, XXXI., pp. 631–72, Plates XXXIII–XXXVII.

[3] Lapworth, in Armstrong, Young & Robertson's Cat. West Scottish Fossils, Glascow, 1876.

[4] Geol. Mag., London, IV., pp. 107–13, Plate VII.

[5] Ann. and Mag. Nat. Hist., 1880, V., pp. 171–4.

[6] Trans. Roy. Soc. Can., X., pp. 95–100, Plate VII.

[7] Geol. Mag., VIII., pp. 20–6, 1 pl.

[8] Intellectual Observer, London, XI., p. 369, Plate II., Figs. 16*a–c*.

[9] Trans. Roy. Phys. Soc. Edinb., I., pp. 367–70.

[10] Geol. Mag., V., p. 132, Plate V., Fig. 6*a–c*.

[11] v. Baer u. Helmersens Beiträge z. Kenntn. d. russ. Reichs, St. Petersb., VIII., pp. 45–6, Plate I., Fig. 6. *Graptopora socialis*, Salter, is a synonym.

[12] Öfv. k. Sv. Vet. Akad. Förh., XXXVIII., No. 9, p. 45. Type *H. expansus*.

[13] Ann. and Mag. Nat. Hist., IV., pp. 231–42, Plate XI.

[14] *Loganograptus* is recognized by some authors. I can see in the compound forms only two fairly good genera, *Dichograpsus* and *Schizograpsus*, though a number of (mostly unispecific) genera have been proposed. The type of *Loganograptus*, however, is *L. logani*, and *headi* is a *Tetragrapsus*.

[15] British Palæozoic Fossils, pp. 3–9, Plate I*b*.

[16] Histoire des Végétaux Fossiles (4°, Paris), pp. 70–71, Plate VI, Figs. 7–12. Brongniart's *Fucoides dentatus* and *F. serra* are the (subsequently described) *Graptolithus pristiniformis* and *G. bryonoides* of Hall respectively.

[17] Trans. N. Y. Acad. Sci., 1895, pp. 262–73, Plates XLVIII., XLIX. His *Clonograpsus spinosus* of 1893 (see note 6, above) is referred to *Bryograptus*.

[18] Amer. Journ. Sci., p. 401.

[19] Geol. Mag., IX., p. 508.

[20] G. Scalaris (Linn.) Hall, 1847, Pal. N. Y., I, p. 271, Plate LXXIII., Figs. 4*a–g*. Of these figures, *a* and *b* are *Climacograptus bicornis*; *c* and *d* are *C. typicalis*; *e* and *f* are *Didymograpsus Sagitticaulis*; and *g* is *Climacograptus parvus*.

R. R. Gurley, M. D.

U. S. Geological Survey.

EDITORIAL.

GEOLOGISTS who are interested in the more obscure problems of the physics of the earth will welcome with peculiar gratification the appearance of a monographic periodical devoted to one of the most neglected phases of the earth's phenomena, "TERRESTRIAL MAGNETISM, An International Quarterly Journal," published under the auspices of the Ryerson Physical Laboratory of The University of Chicago. The journal is edited by Dr. L. A. Bauer, with the coöperation of thirty-four eminent students of terrestrial magnetism, representing sixteen countries, among which the European states naturally predominate, but China, Java and Australia appear as representatives of the antipodes. The magazine will perform a valuable service in bringing together matter which is now so widely scattered as to be difficult of access even to specialists, and quite beyond the reach of most geologists. Without doubt it will also greatly promote the organization of the matter and the evolution of the science. Not a few geologists have looked with some measure of hope to terrestrial magnetism for a valuable contribution to the dark problems of the earth's interior. We have long felt that there should be discoverable some medium which could be operated upon by some inventible device in such a way as to serve as a stethoscope, so to speak, to declare the conditions and the changes in the heart of the earth. Magnetism is one of the suggested media, and, even if it shall not prove an agency of any great moment in itself, it may reveal conditions of the interior now quite hidden from us. The editorial greeting pertinently quotes Maxwell's eloquent words—referring to the sensitized sheet of the self-registering magnetograph—"On that paper, the never resting heart of the earth is now tracing in telegraphic symbols,

which will one day be interpreted, a record of its pulsations and its flutterings, as well as of that slow but mighty working [the secular variation] which warns us that we must not suppose that the inner history of our planet is ended."

The first number of the journal contains several articles of weighty interest to geologists.

T. C. C.

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THE Geological Society of America held its eighth annual meeting in Philadelphia on the 26th, 27th and 28th of December, under the presidency of Professor N. S. Shaler. The attendance was large, embracing a considerable proportion of the geologists residing east of the Mississippi River. Professor Joseph Le Conte was elected president for the ensuing year, and Professors C. H. Hitchcock and Edward Orton, vice-presidents. The secretary, treasurer and editor, Messrs. Fairchild, White and Stanley-Brown, respectively, were reëlected. Professors W. K. Brooks, of Baltimore, and W. H. Norton, of Mount Vernon, Iowa, and Messrs. H. F. Bain, Des Moines, Iowa, C. R. Eastman, Cambridge, Mass., H. B. Kümmel, Trenton, N. J., F. B. Taylor, Fort Wayne, Ind., and J. B. Woodworth, Cambridge, Mass., were elected fellows of the society. On the evening of the 27th, Professor Scott, of Princeton, gave a public lecture on the Tertiary Lakes of the West. The presidential address of Professor Shaler on *The relations of geologic science to education*, was delivered on the morning of the 27th. Papers were presented in the regular sessions by the following members: J. F. Kemp, N. S. Shaler, W. M. Davis, L. V. Pirsson, F. P. Gulliver, M. R. Campbell, N. H. Darton, C. R. Van Hise, Robert Bell, Alfred C. Lane, Harry Fielding Reid, Frank Leverett, G. Frederick Wright, H. L. Fairchild and C. H. Hitchcock. Although other names appeared on the printed programme, their papers were not read Abstracts of some of these papers appear in this number of the JOURNAL. The papers covered a wide range of subjects. While many of them were of much interest, few of them provoked

lengthy discussion, and none of them antagonistic criticism. The meeting added one to the list of pleasant and profitable sessions which the society has enjoyed.

R. D. S.

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It has been found necessary to postpone the articles of Dr. Van Hise, announced in our last issue, for one or two numbers. The continuation of the "*Glacial Studies in Greenland*" has also been postponed to make room for other matter.

A circular letter containing a slip for insertion in the last number of the Journal, correcting our unfortunate error regarding Dr. Dawson, was mailed to all subscribers. If it has failed to reach any we will be glad to supply it on being informed of the fact.

C.

Reviews.

The Hill Caves of Yucatan. A Search for Evidence of Man's Antiquity in the Caverns of Central America, being an account of the Corwith Expedition of the Department of Archæology and Palæontology of the University of Pennsylvania. By Henry C. Mercer. Philadelphia: J. B. Lippincott Company; 1896. 8vo., 183 pp., 1 map, 74 illustrations.

In the introduction attention is called to the important results of cave exploration in Europe, and the slight work previously done in America. Brief reference is made to the author's explorations in Pennsylvania, Virginia, West Virginia, Tennessee, Kentucky, and Indiana, during the previous two years, and their uniform negative results, so far as evidence of a primitive race or great antiquity is concerned, although abounding in evidence of Indian occupation. It was hoped that the caves of Yucatan would afford decisive evidence. They were large and abundant; were open, light, dry, and accessible; were on or near the line of communication between the ruined cities of Uxmal, Labna, Mayapan, Ticul, Mani, and Chichenitza, and were during the dry season almost the only natural sources of water supply. "If ever human refuse layers on the floors of caverns were to reveal the conditions of a lost human chronology, such layers might be looked for in these caves, the first group of which existed, as we were told, at Calcehtok, and the second at Tabi, about half way on a straight line between Uxmal and Ticul."

About two months were spent in the search. Twenty-nine caves were visited, thirteen of which had archæological significance. "Six yielded valuable, and three decisive results." Human relics were found in abundance in the upper layers of the earthy floor of the caverns, but not in the lower layers (except as occasionally found in animal burrows). Of the fourteen feet of cave earth found resting on the solid limestone floor, in one of the most satisfactory excavations, only the upper six contained human relics, while the lower

eight feet gave no evidence of man, although yielding remains of animals to the bottom indicating the early accessibility of the cave. In general, the depth of cave earth was less than this. The human relics were abundant but not varied in kind and implied but one type of civilization. Potsherds were by far the most abundant, some decorated with incised lines and a few colored. Only a few implements were found. Human bones were occasionally present. Of the vertebrates identified by Professor Cope there were three batrachians, six reptiles, nine aves, and sixteen mammalia, thirty-three species in all. Members of each of these groups were found beneath the relic-bearing layer at depths varying from six to fourteen feet, twenty-two instances being tabulated. Of the shells, eleven species were identified by Pilsby; eight instances of occurrence below the human layer being tabulated. These data show abundantly the accessibility of the caves before the incursion of man.

The author's conclusions are: "*First*, That no earlier inhabitant had preceded the builders of the ruined cities in Yucatan.

"*Second*, That the people revealed in the caves had reached the country in geologically recent times.

"*Third*, That these people, substantially the ancestors of the present Maya Indians, had not developed their culture in Yucatan, but had brought it with them from somewhere else." T. C. C.

New Evidence of Glacial Man in Ohio. By Professor G. Frederick Wright. Appleton's Popular Science Monthly, December 1895.

The "fresh discovery recently brought to light," which constitutes the subject of this article, is, in reality, a discovery made more than three years ago. It therefore antedates the recent controversy respect ing the evidence of glacial man in America which the author revives and makes his point of departure, and on which he strives to bring to bear this evidence as something recent. The central point of that controversy was the untrustworthiness of the old methods of observing and interpreting the supposed evidence of glacial man. The sharp criticisms which provoked it were sorely needed, as the event has shown, to reform the loose methods then prevailing. This "fresh discovery" belongs to the ante-reform period, and is to be weighed accordingly.

Announced as such, it deserves consideration, for it is one of the better class of examples of the old method.

The nucleus of the article consists of a statement by Mr. Sam Huston, a surveyor and collector, under date of August 13, 1895, of the finding, over three years previous to that date, of a rude stone implement, in a gravel terrace near Brilliant, on the Ohio River. The terrace ranges from 65 to 80 feet above low water, and consists of interstratified sand, fine gravel, and clay in small quantities, all with rare exceptions cross-bedded. "Indian mounds and intrusive burials occur at numerous places on the terrace, but the stratification and the cross-bedding of the sands and gravels of it are such that intrusive burials or excavations cannot be made without leaving evidence so distinct as to be readily seen, and at the face of the excavation a slip or talus is easily detected." The flint implement was found "under about eight feet of undisturbed cross-bedded stratification, only the point of the implement showing on the perpendicular face of the excavation. The condition of the stratification in all of the superincumbent eight feet, which was closely examined by me, was such as to convince me that the implement was not intrusive, but had been deposited with the remainder of the material of the terrace" (Huston).

Mr. Huston's observations may fairly be accepted as excluding intrusive burial by Indians, but they do not seem to exclude intrusion by modes which do not notably disturb the stratification, for these do not appear to have been in mind at the time of his observations and would not naturally obtrude themselves upon attention. These neglected modes of intrusion were discussed at the meeting of the American Association for the Advancement of Science at Madison, but this was some time after Mr. Huston's observations were made, and he obviously could not avail himself of the suggestions there offered. Particularly applicable to the present case is the mode of intrusion offered by the decay of tree roots, as this is not only a forest region, but the elevation of the terrace, the porosity of the sand and gravel, and the low water level especially invited the deep penetration of large roots. Allowing a hundred years for a generation of trees, there falls within the conventional historical period of 6000 years, the possibility of sixty successive forests. This may serve to suggest in a rude way the large number of root-tubes which may have been opened by decay and afterwards filled in relatively modern times. It is a well-known fact that decay commonly starts at the surface and proceeds down-

ward, and thus invites filling from above. It is furthermore often the case, perhaps indeed the rule, that the bark of roots decays more slowly than the interior, thus preserving the tube for a time after it is open to intrusion from above. In the growth of the trees the roots heave the earth about the base of the trunk, and this raised position is obviously the first to collapse on the initiation of decay. Now there are special reasons why implements were somewhat more likely to be lost about the base of a tree than elsewhere, for its shade was naturally sought for rest, for shelter, for sedentary work, such as the making and repairing of implements, for the gathering of nuts, for climbing, and for a multitude of incidental reasons. Missiles, though not in point in this case, were likely to be arrested by trees, especially as they were often directed at game in them. The mounds and intrusive burials mentioned by Mr. Huston imply that this was a frequented spot, and that lost and discarded implements would be not uncommon. Articles lost at the immediate foot of a tree would be liable to fall into the stump cavity on its decay, or to be trodden into it, and to follow down the root tubes as the rotting progressed. With the prolonged decay of the centuries the organic matter disappears in such porous beds, and the signs of intrusion become exceedingly obscure. It would be a rash geologist who would claim that he had detected all of the multitude of refilled root-tubes of a possible three score or more of generations of forests in an inspection of a gravel bank, unless he most assiduously searched for them. It is no detraction, therefore, from the assumption of fair competency or perfect honesty on the part of the observer, to withhold complete confidence in the inspection of Mr. Huston, so far as it is supposed to exclude intrusion by the more occult methods of which this is a type, though his observations may fairly be assumed to exclude intrusion by burial, to which his attention was directed.

Following the statement of Mr. Huston, the author discusses the vital question of the age of the gravels. He calls attention to a line of terraces resting on rock shelves about 300 feet above the river (*i. e.*, 220 feet above the implement-bearing terrace). These bear granitic pebbles, and are appropriately referred to the glacial period. They occur at intervals along the Ohio up to its head, and follow the Allegheny River so far as it skirts the glacial border. He notes the opposing views entertained respecting the age of these, rejecting that which involves two glacial epochs separated by the erosion of the gorge in

which the lower terrace lies. He maintains on his own part that the evidence of two distinct glacial epochs is insufficient, and holds that "the deposits of glacial gravel upon the three-hundred-foot rock shelf have been produced partly by an extensive filling up of the Allegheny gorge as far as Pittsburg and somewhat below, and lower down by the effect of the Cincinnati ice-dam, which set back the water up to this level, and is sufficient to account for many of the facts. Under this view these high-level deposits would coincide approximately with what Dana calls the 'Champlain epoch,' during which there was considerable depression of land at the north, the influence of which may have been felt as far south as the latitude of Pittsburg."

The rejection of interglacial erosion, and the introduction of the Cincinnati ice-dam as an agency seems to the reviewer to very greatly weaken the case. The unfortunate ice-dam hypothesis was originally urged as specially applicable to the high-level terraces of the upper Ohio and its tributaries; indeed it may be said to have had in them its *raison d'être*, but investigation has shown that it is altogether untenable. The author himself has been forced to abandon it for the upper region where the phenomena are conspicuous and have been competently studied. It is safe to say that the same fate will befall it in its application to the terraces farther down the river, for they are of the same order and have the characters of river terraces and not those of ponded-water terraces. Any interpretation hung on the ice-dam hypothesis is quite certain to have an early fall. Excluding this, it is either necessary to suppose that the valley was eroded to a depth of more than 220 feet (either in drift or in rock) before the floods of the later glacial epoch formed the lower terraces, or to regard these lower terraces as remnants of the high-level filling cut into terrace form in later times and more or less *re-worked* on the surface in the process. If the supposed high-level filling really occurred in the time of the Champlain depression, to which the author refers it, very much the largest part of all the erosion that has taken place since must have occurred before the implement-bearing terraces were formed, and, accepting the general estimates of post-glacial time favored by the author, this might not impossibly bring their formation this side of the reign of the Pharaohs.

But in reality the author assumes that the great interglacial erosion took place (though he has not yet come to call it interglacial, and he would probably still wish it understood to be a reëxcavation) for he

says that every stream emerging from the glacial area is marked by the lower system of terraces, and some of these enter the Allegheny-Ohio valley in that portion which the author admits to have been filled up to the high-level terrace plane, and the low terraces could only have been formed after the requisite deep excavation. It is also implied in the following, which calls for consideration on other grounds: "But whatever may be the difference of opinion about the age of these high-level gravels, there is no disagreement about the glacial character and relatively late age of the lower terraces along the Ohio River such as occur at Steubenville and Brilliant." In a loose sense it is true that the glacial character of these lower terraces is agreed upon, but this is a case in which no looseness is admissible. In a general way it may be said that the gravel deposits out of which these terraces have been cut were formed by the late glacial waters, but only a portion of them are strictly primary and retain the original surface of the deposits. Many of them are secondary in greater or less degree. Their upper plains were not formed in glacial times, but were fashioned by erosion out of the earlier deposits, and were *reworked* in the process. The extent to which the Ohio River then reworked its bed may doubtless be judged by what it is doing now. The vertical range of the material which it is now working over is several times the depth at which the implement was found. It is quite necessary therefore to know whether the upper part of the Brilliant terrace is primary or secondary. There are terraces on the river above and below it that reach 120 and 130 feet above low water, while the implement-bearing terrace only reaches eighty feet. Here is a difference of a round third of the maximum height. If the difference is due to erosion it seriously compromises the case, for the date of the fashioning of the terrace might be quite late, and the implement might have been introduced in the reworking incident to it. The difference may, of course, be in part, or possibly altogether, due to original difference in height. But this must be *demonstrated* to make the case good. If it is merely assumed that the terrace surface is original, the conclusion dependent on it suffers all the uncertainties of the assumption.

The nature of the implement is discussed in the article, and the opinions of several archæologists respecting it are given. It is pronounced to be one of a very ancient form which has, however, always continued in use.

The author indicates his views of the environment of the time as

follows: "In closing I cannot refrain from a few remarks concerning the conditions of life at that period, especially since the prolonged visits which I have made to the retreating ice front in Alaska [a month in midsummer] and in Greenland [two or three weeks in August] have rendered it so much easier for me to believe in glacial man than it would have been without those experiences. The neighborhood of the ice border during the glacial period was probably not an uncomfortable place in which to live." And again, in respect to conditions unfavorable to relics—"When we reflect, also, upon the completeness with which the habitations of the modern Indians have disappeared, we need not be surprised at the total disappearance of the habitations of glacial man. Nor is it strange that well-accredited discoveries of his implements have so rarely been made in the undisturbed gravel which gives us the surest evidence of his great antiquity. Naturally, the cautious inhabitant of that time would have been somewhat careful about venturing down into the river valleys, whose terrific and periodical floods were depositing the terrace gravel." And yet we are expected to believe that these terrific, fear-compelling floods made a deposit of sand, fine gravel, and clay in which, "except for two or three feet on top, only rare pieces of gravel occur of more than one half cubic inch in size" (Huston). T. C. C.

Fossil Sponges of the Flint Nodules in the Lower Cretaceous of Texas. By J. A. Merrill. Bull. Mus. of Comparative Zoölogy at Harvard College, Vol. XXVIII., pp. 1–26, 1 plate, July 1895.

This paper is the first contribution to the minute structure and organic remains of the flints found so abundantly in the Caprina limestone of the Lower Cretaceous of Texas. Mr. Robert T. Hill, in several preliminary papers, has described their geological occurrence.

The studies set forth in this paper were based upon a few nodules brought to Cambridge (Mass.) by Mr. E. E. Cauthorm, from a quarry west of Austin, Texas.

"The hardness of these nodules," our writer says, "is often greater than that of glass. . . . In shape they are spherical, cylindrical, or flat; and in size they vary from two inches to a foot or more in diameter. The color is a dense black, with white or gray spots mixed irregularly through it, varying in size from microscopic to that of a pin-head. These spots are generally replacements of organic remains,

and, when such, are, in all cases that I examined, chalcedonic silica; the larger ones showing the structure characteristic of chalcedony. . . . The outside of the nodule is composed of a layer of chalk one-quarter to three-quarters of an inch in thickness, cemented with infiltrations of silica." Generally there was only one layer of the chalky substance, but in one nodule four alternations of this material with layers of solid amorphous silica were observed.

Preparatory to studying, the flints sections were cut in various parts of the nodules and at varying directions, so as to discover if there was any difference in the character of preservation, etc.

The origin of the nodules is assumed to be the same as that of those in England and on the European continent, *i.e.*, "that the source of these stones is organic silica, and that the principal source of this silica is the framework of silicious sponges." This conclusion is considered justified "from the great similarity of physical characteristics of nodules and surrounding materials in the Cretaceous of Europe and America, and also from the fact that the included fossils are of the same families and genera."

Remains of the following organisms were found: Foraminifera, were in every slide, and were represented by *Globigerina* and *Textularia*. Sponge spicules, were very numerous; and imperfect remains of mollusks and fish scales were present.

To the condition of the preservation of the sponge spicules considerable attention is given. They were found in all stages of preservation, but excepting the globo-stellates, very few were perfect. Sometimes numerous faint tracings of spicules merged, so that their outlines could not be followed, more often, however, they were separately imbedded in amorphous silica. The canal usually showed a separate crystallization from the body. Its size varied greatly, sometimes there being only a ring of crystalline silica on the outside. The canal may be replaced by dark opalescent silica, or it may be hyaline in appearance.

The globo-stellate spicules were composed, in most cases, of amorphous silica, and Mr. Merrill suggests that they may represent the colloidal silica originally deposited by the sponge. In these spicules evidence was found corroborating the experiments of Sallas, viz., that the globo-stellates are dissolved from the center outward. This is illustrated in Fig. 22, in which the center portion of the spicule has been entirely dissolved and only the spines are left. Some spicules were replaced by peroxide of iron.

After the discussion of the conditions of preservation a comparison is made with some chert from Croydon, England. The chert, instead of being composed of amorphous silica, was made up of "a dense aggregation of entangled spicules."

In classifying the spicules of course the classification of Zittel was followed. Representatives of the Monactinellids, Tetractinellids, Lithistids (?) and Hexactinellids were found. Mr. Merrill introduces but few new names, contenting himself with describing and figuring the spicules the best that he could. For eight of the forms figured he proposes names, recognizing however that later, several of the different spicules may be proved to belong to the same species.

Of the various groups, the Tetractinellidæ are the most abundant, and, strange to say, the dermal or flesh spicules are the most numerous, and are the best preserved. This is the reverse of what has been found by the students of the European cherts and flints. The writer of this review has found the same condition prevailing in the slides of the Texas flints that he has examined, as Mr. Merrill describes. The globo-stellates are the most abundant and best preserved.

The following are the names proposed by Mr. Merrill: *Geodia? spini-curvata*, *Geodia ? cretacea*, *Geodia ? austini*, *Geodia ? irregularis*, *Geodia ? tripunctata*, *Geodia ? texana*, *Geodia ? spini-pansata*, *Geodia ? hilli*.

A single spicule of a doubtful Lithistid was found. The Hexactinellidæ were but poorly represented.

In discussing the process of formation of the nodules the theories advanced by Wallich and Sallas are first given. Then Mr. Merrill states that in the nodules studied by him the spicules were more perfect in the body of the nodule than near the surface, those near the surface showing crushing and mechanical wear. "The mechanical crushing differed considerably in the different specimens, and one showed complete obliteration of the spicular structure." In the sponge spicules studied by Carter, Sallas and Hinde, all of which had been subjected to mechanical movement, the smaller spicules had been destroyed. Carter says that he did not find minute stellates or spines, or tubercles or the large spicules in the Haldon deposit. Sallas says that the once existing spicules are absent, because they have been dissolved. Hinde says that "flesh spicules are rarely met with in the fossil state." In the Texas flints a scarcity of zone spicules and a great number of flesh spicules, preserved in the greatest perfec-

tion, were found, precluding, Merrill believes, that they could have been subjected to any friction or great mechanical movement. From the state of preservation of the spicules the conclusion is reached that the nodules were formed in situ, and that each nodule represents "a separate sponge bed." The following is Mr. Merrill's theory: "On the death of any certain part, the spicules fell away, many of them fall down below into the mass at the bottom. Here the process of solution went on continually, and nearly all the spicules were dissolved and few left in the dissolved mass. Why so many of the dermal spicules are left and the zone spicules nearly all dissolved is hard to account for, and I have no explanation to suggest. Many of the spicules would doubtless fall outside of the growing mass, and these might be dissolved according to the method suggested by Dr. Wallich elsewhere quoted, and by movement through the water settle around the masses already dissolved, and thus form the concentric rings above referred to, and also account for the broken condition of the peripheral spicules. This would also account for the fact that each nodule had a prevailing number of spicules peculiar to itself while a few were common to all." The form and size of the nodules is thus explained: "If the sponge takes root in the ooze of the ocean and becomes firmly imbedded, there will be at its bottom a considerable cavity where the bottom part dies. We have no means of knowing how rapidly the oozes accumulate, but if they accumulate as rapidly as the dissolved silica accumulates, then it would seem that the ooze might enclose a pocket of the silica, having grown up around the base of the sponge. In this way the flint nodule would grow as the sponge mass may have been expected to grow; namely, it would begin small, reach a maximum size, then decrease in size, and finally end in a point as it began."

The theory of the formation of the zones seems weak, because it does not appear probable that the spicules would fall with sufficient regularity to make a concentric ring. According to the theory propounded by Mr. Merrill he seems to be of the opinion that the flints stand with their long axes vertical. The long axes lie in a horizonal plane.

The observations of Murray, that sponge spicules collect around shells, is noted, and is considered a probable hypothesis, but Merrill does not consider it applicable to the nodules studied by him. Mr. Hill has noted the occurrence of *Monopleura texana* as a central nucleus of some of the flints found in Comanche county, specimens of

which are now in the United States National Museum, but these did not come under Mr. Merrill's observation. It must be noted in this connection that Mr. Merrill's material was proportionally very limited in comparison to the vast extent, variation and stratigraphic zones of the flints in Texas, and the only cause for regret is that he did not have a more extensive collection for study.

Regarding the depth of the water in which the flints were formed, only a very general conclusion was reached, viz., it was beyond the continental shelf, but not in the deepest sea.

The plate accompanying the paper is made up of thirty-six figures drawn by J. H. Emerton. The size of the objects figured was very carefully determined by micrometer measurements.

The author should be complimented on the painstaking manner in which he has done this important work, and it stands as the first careful microscopic research into any part of the great series of chalky limestone sediments in the two great series of the Cretaceous in Texas.

T. WAYLAND VAUGHAN.

Thirteenth Annual Report of the State Geologist (New York) for the year 1893. JAMES HALL, State Geologist.

This report consists of two volumes, the first devoted to geology and the second to palæontology. The papers published in Volume I. may be divided into two sections: first, those relating to the Livonia salt shaft, and second, papers on geologic work being done in connection with the preparation of a new geologic map of the state.

In November, 1890 the Livonia Salt Company began the sinking of a shaft of 12 x 22 feet, 1432 feet in depth, at Livonia, Livingston county, New York. Detailed records were not preserved for the first 380 feet, but from that depth to the bottom, Mr. D. D. Luther, in the employ of the state geologist, kept a careful record of the stratigraphy and collected great numbers of fossils, accurately recording their horizons. The strata penetrated were as follows: Drift (64 ft.), Portage (55 ft.), Genesee (161 ft.), Hamilton (517 ft.), Marcellus (69 ft.), Corniferous (132½ ft.), Onondaga (2½ ft.), Oriskany (5 ft.), Lower Helderberg (112 ft.), and Salina (314 ft.). This is probably the most extensive continuous section of stratified rocks that has ever been submitted to such a detailed study, and the papers relating to it

bring out many interesting facts, especially that of Professor Clarke on *The Succession of Fossil Faunas.*

The following papers relating to this shaft, illustrated by numerous maps, charts and plates, are incorporated in the report:

The Livonia Salt Shaft, its History and Geological Relations, etc. By James Hall.

Report on the Geology of the Livonia Salt Shaft. By D. D. Luther.

The Succession of the Fossil Faunas in the Section of the Livonia Salt Shaft. By J. M. Clarke.

New or Rare Species of Fossils from the Horizons of the Livonia Salt Shaft. By J. M. Clarke.

The remainder of Volume I. is devoted to the following geological papers:

Report on the Relations of the Helderberg Limestones and Associated Formations in Eastern New York. By N. H. Darton.

Preliminary Report on the Geology of Albany County. By N. H. Darton.

Economic Geology of Albany County. By F. L. Nason.

Preliminary Report on the Geology of Ulster County. By N. H. Darton.

Economic Geology of Ulster County. By F. L. Nason.

Geology of the Mohawk Valley in Herkimer, Fulton, Montgomery and Saratoga Counties. By N. H. Darton.

Preliminary Report on the Geology of Essex County. By J. F. Kemp.

Preliminary Report on the Geology of Clinton County. By H. P. Cushing.

Report on a Preliminary Examination of the General and Economic Geology of Four Townships in St. Lawrence and Jefferson Counties. By C. H. Smyth, Jr.

Report on the Geology of Cattaraugus and Chautauqua Counties. By F. A. Randall.

Report on Field-work in Chenango County. By J. M. Clarke.

A List of Publications Relating to the Geology and Palæontology of the State of New York, 1876–1893. Compiled by J. M. Clarke.

Volume II. of the report contains the following palæontological papers:

Evolution of the Genera of the Palæozoic Brachiopoda. (*Extract from Palæontology of New York, Vol. VIII., Part II.*). This is a valuable paper summing up the conclusions to which Professors Hall and

Clarke have arrived during their prolonged study of this important group of fossils.

Descriptions of New Species Figured in Vol. VIII., Part II.

Platycnemic Man in New York. By W. H. Sherzer.

A Discussion of the Different Genera of Fenestellidæ. By G. B. Simpson.

Glossary and Explanations of Specific Names of Bryozoa and Corals Described in Volume VI. Palæontology of New York and Other Reports. By G. B. Simpson.

The last paper in the report is, *An Introduction to the Study of the Brachiopoda, Intended as a Handbook for the Use of Students. Part II. By James Hall, assisted by John M. Clarke.* Part I. of this handbook was published in the eleventh annual report of the state geologist. Part II. contains generic descriptions and illustrations of the articulate brachiopoda formerly known as the *Spiriferidæ, Terebratulidæ, Rhynchonellidæ* and *Pentameridæ.* A new classification has been adopted by the authors, but most unfortunately the genera are not arranged in the body of the work in accordance with the *Table of Classification* given at the end. The grouping of the genera into families is not indicated in the text, and in some cases genera placed in the same family in the *Table of Classification* are widely separated in the text.

As in Part I. so in this second part, the most striking feature of the work is the multiplication of generic terms. This breaking up of large, loosely defined generic groups into smaller, sharply defined groups of species is a convenience to the student, and allows the arrangement of the genera into a more natural classification.

The genus *Spirifer* has been left intact, though divided into six sections of less than subgeneric rank. Part of these at least are fully as much differentiated as some of the subgenera, of *Athyris* for instance, which are recognized. Among the spire bearing forms or *Helicopegmata*, the authors have recognized their genera strictly upon the differentiation of a single structure, the brachidium. This is an important structure of the organism, but its differentiation should not be considered as the only important one. The differences in the organisms represented in the fossils by the fine longitudinal striæ in *Spirifer radiatus*, and the concentric bands of peculiar double-barreled spines in *Spirifer lineatus*, were probably as fundamental as the differences of the brachidium upon which the subgenera of Athyris are established. If these sections be not of at least subgeneric rank,

then surely *Ambocœlia* is not worthy of separation from *Spirifer* as a distinct genus.

The work as a whole is a valuable acquisition to the literature of palæontology, and will be warmly welcomed by all students of the brachipoda.

S. W.

Istidens foraminiferer i Danmark og Holsten og deres betydning for studiet af istidens aflejringer [The foraminifera of the Ice-Age in Denmark and Holsten and their significance in the study of the glacial deposits.] By VICTOR MADSEN, Meddelelser fra Dansk Geologisk Forening, No 2, Copenhagen, 1895. 225 pp.

The first part of this paper gives a review of the classifications by different geologists of the drift deposits of northern Europe, England and Denmark. A new classification is then proposed, mainly based on evidences of climatic changes in the Quaternary Age, as the author interprets them from observations in Denmark. His scheme runs as follows:

1). Preglacial sedimentary deposits with a temperate fauna and flora. Weybourn crag, Cromer forest-bed in England.

2). Preglacial sedimentary deposits with a boreal or arctic fauna and flora. Ledamyalis-bed, arctic fresh water-bed in England. Yoldia-clay in eastern Prussia. The older Yoldia-clay in Vendsyssel, Denmark (?).

3). Morainic deposits from the Norwegian ice-current in Denmark, northwest Germany, Holland, Belgium, and on the east coast of England.

4). Interglacial sedimentary deposits with an arctic or boreal fauna and flora. Older Yoldia-clay in Vendsyssel ? Yoldia-clay at Esbjerg (Denmark) ? etc.

5). Interglacial sedimentary deposits with a temperate fauna and flora. Cyprina-clay, etc., in Denmark, Holstein, Rügen and Prussia.

6). Interglacial sedimentary deposits with boreal or arctic fauna and flora. Yoldia-clay at Esbjerg.

7). Morainic deposits from the older Baltic ice-current in Denmark, Skåne, northern Germany and northern Holland.

8). Morainic deposits from an ice-current which moved in a direction from N. E. to S. W. in Holland, Skåne and possibly in Denmark.

9). Interglacial sedimentary deposits with arctic and boreal fauna and flora. Older Dryas-clay in Skåne and Denmark.

10). Morainic deposits from the second Baltic ice-current over the lower tracts of Skåne, the Danish Islands, the east coast of Jutland, and the north coast of Germany.

11). Late glacial sedimentary deposits with arctic fauna and flora, perhaps partly of the same age as the preceding. The latest Yoldia-clay in Vendsyssel, Sweden and Norway. Latest Dryas-clay in Skåne, Denmark, and northern Germany.

12). Late glacial sedimentary deposits with boreal fauna and flora. Glacial shell-beds in Sweden and Norway, Zirphæa-bed in Vendsyssel.

"This classification of the diluvial deposits," the author says, "is only a hypothesis, but it appears to me that it better than those in use heretofore explains the many intricate relations of the drift, and that it will serve better than these as a working hypothesis in geological investigations on the diluvial deposits of Denmark. It hardly rests on any more uncertain foundation than the hypothesis in vogue at the present time, and like all these it is very much in need of verification." The first ice period in Geikie's classification, that represented by the Weyburn crag, is set aside expressly, and so is also Geikie's fifth glacial period. The Norway ice-current is believed to have been older than the oldest Baltic ice-current, and the opinion is expressed that the time of the former was separated from that of the latter by an interglacial period, during which the ice left the land entirely. The evidence adduced in favor of this view is the presence of Norwegian bowlders in the lowest moraines in Denmark, and in the drift which lies south of the southern border of the Baltic moraine in northern Europe. It is not considered as probable that the Norway current could have been diverted by the Baltic current to such an extent in the same glacial period, as to have first deposited its material in northern Denmark, and later on in the same age have laid down its moraine in England.

The author urges the importance of the study of the fossils of the drift. The greater part of the paper gives the results of his studies of the foraminifera in the drift of Denmark. These fossils are small and have often been well preserved, where larger fossils have been crushed. These organisms are marine, and when found, they often give decisive evidence as to the circumstances of their deposition, for many of them are dependent on certain conditions of climate and

on the depth and relative saltness of the sea. In studying the marine diluvium of Denmark, the author has found it insufficient to make the basis of classification consist of the structure of the beds and the character of the previously known fauna only. He now proposes the following classification based on the differences in the foraminifera contained in these beds.

a. Deposits with a temperate fauna, comprising formations of interglacial age (probably in every locality studied). A part of these beds seem to belong to an age of comparatively warm climate, while another part appears to belong to a period of comparatively cold climate.

b. Deposits with an arctic or boreal fauna. This division comprises:

I. The older Yoldia-clay.

II. The later Yoldia-clay.

III. The Zirphæa-bed.

The Cyprina clay belongs to the deposits that have a temperate fauna. Of its 13 foraminifera, eight forms are cosmopolitan in their habitat, two are found in southern waters, ranging as far North as to the Shetland Islands, while two are northern forms occurring as far South as Valencia. One form is not known in the present seas. This indicates climatic conditions identical with the present. The nature of the molluscan fauna of this clay corroborates this evidence. A summary is made of the literature on the structural relations of the Cyprina-clay. While the author admits that its exposures, so far as observed in Denmark, do not decidedly speak against the view that it is preglacial, he believes that there are good grounds for regarding it as being formed later than the oldest border clay on these islands. It has in no place been seen in an undisturbed condition under the bowlder clay and resting directly on preglacial deposits. The bowlder clay associated with it often contains a large number of foraminifera, but it lacks those forms which are characteristic of the Cyprina-clay. Hence this bowlder clay can not very well be later than the Cyprina-clay, for, if this were older some of its fossils would have been likely to have become mixed into the superimposed morainic material. The high and varied tilting of the bed in most localities indicates, however, that it has been disturbed by glacial action at some time. In samples of a gray clay from Jutland, the author has found a fauna also indicating a temperate climate.

In Holstein several localities have beds of gravel, sand, and clay with foraminifera and molluscs indicating biological conditions

"answering to those now obtaining between western part of Norway and the British Islands." These beds are regarded as interglacial except in one instance, where they are seen to rest on tertiary rocks. They are probably not all of the same age. From three other localities 19 species of foraminifera have been collected, and these indicate a climate like that now prevailing about the Lofoden Islands. The structural relations in this case are unknown.

The author evinces a particular acquaintance with the geology of the Yoldia-clays. The older Yoldia-clay contains Norwegian bowlders but lacks any admixture of materials carried by the Baltic ice, the moraine of which overlies it unconformably. This clay may have been laid down either right before or soon after the invasion of the Norway ice-current. At any rate it was there before the last advance of the Baltic ice. From the 64 species of foraminifera, which have been identified as occurring in this bed, it is inferred that boreal and arctic climates prevailed during its forming. Such indications also exist in the molluscan fauna. The dissimilarities among some of the localities render it probable that all of these do not belong to exactly the same age. In most places this clay has been either tilted or contorted by subsequent glacial action.

The later Yoldia-clay is never overlaid by morainic material and is always found undisturbed. For this reason it is separated from the older clay. It was probably formed soon after the last glaciation of the northern part of Denmark, and possibly in part at the time of the second Baltic ice-current, which probably did not reach this region. This clay has yielded 36 species of foraminifera: 24 are cosmopolitan, four are arctic forms. Of the mollusca most of the forms are now found near Spitzbergen and Greenland. The fauna has a more decided arctic character than has that of the older Yoldia-clay.

The Zirphæa-bed has been observed only on the northern point of Jutland. It resembles the Swedish and Norwegian glacial shell-beds and consists of gravel and sand. Its fossils are found *in situ* and also worked down into the underlying Yoldia-clay. Of the 41 species of foraminifera found, 26 are cosmopolitan, four are arctic and boreal, five occur in the North Atlantic. From this and from the nature of the molluscan fauna, it is inferred that the climate prevailing when this bed was forming, was almost arctic, resembling the present conditions on the west coast of Finland.

Samples of non-marine clays have also been examined, and the

author has found in these (white glacier clay and other fresh water clays) a much smaller number of foraminifera, some of which are certain to belong to the underlying older formations of the Tertiary and Quaternary ages. This is just the reverse of what is the case in the marine deposits, in which foraminifera are abundant and in which specimens belonging to the older formations are exceedingly rare.

These minute animal remains, therefore, give important evidence as to (1) the physical condition under which deposits are made, whether in the open sea, fiords, or in lakes; (2) the climatic conditions, and (sometimes) (3) the geological age.

An appendix contains an annotated catalogue of the 86 species of the foraminifera found in the marine diluvium of Denmark; a map indicates the localities where the samples of the drift examined have been taken, and a plate illustrates several species, one of which is new.

The paper is evidently prepared with care and after a thorough study of the previous work of other geologists in the same field, and after critical observations on many localities by the author himself. A cautious conservatism pervades the statement of facts and arguments. While expressing his belief that the drift in Denmark can best be explained as the result of three separate glacial periods, Mr. Madsen seems to take particular care not to overrate the significance of such observations as support this theory, and to treat this as a question still in need of a positive answer from that country.

J. A. Udden.

Om Lommalerans ålder. By N. O. Holst and Joh. Chr. Moberg (Sveriges geologiska undersökning, Afhandlingar och uppsatser, No. 149).

One of the localities in southern Sweden regarded as furnishing evidence for an interglacial period is near Lomma station on the coast of Öre sound. Excavations have here been made into a clay, which furnishes material for the manufacture of brick and cement. The deposit is about twelve feet in thickness, it is bedded and lies at a level of about 45 feet above the sea and about 28 feet above the highest postglacial beaches in the vicinity. The authors have lately studied the locality critically, and maintain that the Lomma clay is a marine glacial deposit, and not interglacial, as De Geer contends.

The evidence presented in support of their views is, in the first

place, the absence of any overlying till. An overlying till of insignificant thickness has been observed, as it appears, by only one geologist (Tullberg) in one single locality, and the authors say that this observation was a misinterpretation of the facts. The supposed later till is described as a stony sand, perhaps somewhat "kneaded" into the underlying clay. It is not of morainic nature. It would, at all events, be unlikely that morainic material should have been left by an ice-sheet in one single locality, while nearly all of the clay in the vicinity remained uncovered and undisturbed. The prevalence of arctic conditions at the time of the making of the clay is indicated by the presence throughout the deposit of *gadus polaris*, SABINE, and the marine origin of the clay is evident from the presence of the same fossil and also by the presence of small fragments of marine *coscinodiscus*, of fragmentary spicules of *spongia*, and of no less than 33 species of foraminifera. Attention is called to the fact that the Lomma clay in many respects resembles the glacial clay of central Sweden, and the authors regard it as equivalent to the laminated clays near Sandhammaren and of several other places on the southeast coast of southern Sweden.

The foraminifera of the Lomma clay have been made an object of special investigation by Victor Madsen. From the comparative scarcity of these remains in this clay (such remains being found in abundance in shallow marine deposits in Scandinavia), from the disintegrated condition in which they are often found, and from the total absence of the largest species, he concludes that the tests were transported to their present place, by currents, from their real habitat, and that the clay was probably laid down on the bottom of a bay somewhat shut off from communication with the open sea. The identified forms are referred, with some hesitation, to a late stage in the glacial age, or, in the words of the author, "they bear a late glacial stamp."

J. A. U.

Har det funnits mera änn en Istid i Sverige? [Has there been more than one ice period in Sweden?] af N. O. HOLST, Sveriges Geologiska Undersökning, Stockholm, 1895, 56 pp.

The spirit and method of this discussion, which is essentially a restatement of familiar arguments against the divisibility of the glacial period, are shown by the opening sentence "Even in the domain of

science there is a weakness for what is in mode. When some new view is introduced in a country, the chances for its general acceptance will be materially increased if it has been adopted in another country, or if it is understood to be so adopted. It is only in this way that we can explain how the idea of two glacial periods has gained such a foothold in Sweden as it has today." Much of kindred nature follows, involving personal implications. The section on America is introduced in like fashion. "If any one should think the coincidences of American interglacial proofs corroborate the proofs of European interglacialists, he makes a mistake in so far as that the American interglacial evidences have not been worked out independently, but after European patterns."

Ex. Tr. by J. A. U.

Les Glaciers Pliocènes et Quarternaires de l'Auvergne; par M. MARCELLIN BOULE. Gauthier-Villars et fils, Imprimeurs-Libraires des comptes rendus des séances de l'Académie des Sciences, Paris, Dec. 1895.

Many geologists have studied the ancient glaciers of Auvergne. Rames had observed in the environs of Aurillac glacial formations of two different epochs, separated by a lapse of time sufficient to erode the valleys. While the moraines in the valleys have been accepted as such by all geologists, doubts have been raised as to the morainic nature of the more ancient formations on the summits of the hills and on the plateaux. The author, having devoted himself for several years to the making of a detailed geological map of the Auvergne region, took up the subject in much more detail than had previously been given to it. The volcanic massifs of Mts. Dore, Cezallier and Cantal, form an immense semicircular amphitheater, more than forty kilometers in diameter. The plateaux and the lesser declivities of this cirque present thousands of monticules that show, on the side toward the cirque, gentle slopes, rounded surfaces and moutonnées often furrowed with deep parallel striæ; while the opposite sides present sharp angles and vertical escarpments. Nothing is more curious to the traveler than the difference in the landscape as viewed, respectively, looking toward the amphitheater and toward the valley opposite. Between the monticules there is a labyrinth of meadows, with occasional marshes, underlain with morainic material, including striated flints and blocks of all sizes.

The trains of fluvio-glacial alluvium and erratic blocks into which the moraines pass, cross the deep cut in which the Dordogne flows and reach the hills of Limousin. The phenomena are not to be explained by individual glaciers, but imply the existence of a true ice-cap covering the entire region. The formations here described are only to be seen on the plateaux overlooking the valleys for 100 to 300 meters.

After the erosion of these plateaux during an interglacial epoch, the valleys were occupied by local glaciers. The quaternary age of the moraines formed by these is demonstrated by fossils of various kinds. The glacial formations of the plateaux are referred to the upper Pliocene by a comparison with the phenomena of adjacent regions.

H. C. C.

Neocene Mollusca of Texas, or Fossils from the Deep Well at Galveston. By G. D. HARRIS. Bulletins of American Palæontology, No. 3.

This bulletin is a condensation of a portion of the Monograph of the Marine Tertiary Mollusca of Texas, prepared by Professor Harris but as yet unpublished owing to the lack of funds of the Geological Survey of Texas.

The material described in the bulletin is unique, for up to this date no other marine Neocene fossils are known from the gulf slope west of Mississippi. , Seventy-five species and varieties, twenty-three of which are new, distributed among forty-seven genera, are noted or described in the paper, which is illustrated by four plates.

S. W.

AUTHORS' ABSTRACTS.

[Papers presented at the Philadelphia meeting of the Geological Society of America, December, 1895.]

Preglacial and Postglacial Valleys of the Cuyahoga and Rocky Rivers. By WARREN UPHAM, St. Paul, Minn.

The Cuyahoga River, entering Lake Erie at Cleveland, occupies the same valley as before the Ice Age, but the rock-bed of the preglacial river is more than 200 feet below the present river and level of the lake. About eight miles farther west the mouth of the postglacial channel of Rocky River, eroded nearly 100 feet deep in the Erie shale, is three-fourths of a mile east of the drift-filled preglacial valley, in which a very interesting section of two deposits of till, with intervening stratified sand and fine silt, is seen along a distance of one mile of the lake shore. The glacial and stratified drift deposited in both these preglacial valleys give evidence of a recession and readvance of the ice-sheet during its general stage of formation of the numerous retreatal moraines of the district.

Four shore lines, the highest belonging to the Western Erie glacial lake, and the lower ones to the ensuing Lake Warren, are described in detail in their course through Cleveland, crossing the Cuyahoga valley. The highest or Leipsic beach is traced several miles farther east than it was before known, and is thus found to be correlative with the marginal moraine which extends from Euclid eastward, closely parallel with the lake shore.

In the closing part of this paper the glacial readvance shown by the Rocky River and Cleveland sections is compared with the glacial and interglacial deposits of Toronto and Scarboro', Ontario, which were described by Professor A. P. Coleman in the last September-October number of the JOURNAL OF GEOLOGY (Vol. III., pp. 622–645, with sections). Mr. Upham attributes the fluctuations of glaciation which are thus recorded on the north side of Lake Ontario to a time after the formation of the moraines, stratified drift, and upper till, in the vicinity of Cleveland.

After the deposition of the fossiliferous sand and clay beds of the Scarboro' Heights section, according to the view taken in this paper, an outflow east from the lake basin at Rome began. On account of the depression of the land, which brought on this final Champlain epoch of the Ice Age, the relative height of the land in the vicinity of Toronto, as compared with the depressed region about 190 miles eastward at Rome, then permitted a stream to erode its valley near Toronto to a depth below the present level of Lake Ontario. Later, and after a temporary advance and second retreat of the ice border at Scarboro' and Toronto, forming a thick till deposit, the differential reëlevation of the land, probably 200 to 300 feet more at Rome than in the west part of the Ontario basin, caused the water level of Lake Iroquois to rise gradually on the land westward until it stood at last permanently during many years at the conspicuously developed Iroquois beach.

The uppermost till of the Scarboro' Heights, that is, the second till deposit above the fossiliferous beds, seems to be a retreatal moraine, belonging to the second glacial recession, or to a third retreat after a second slight readvance, all considerably antedating the Iroquois beach, which lies above all these drift accumulations.

A Needed Term in Petrography. By L. V. Pirsson.

The term crystal carries with it an essential idea of outward geometric form produced by plane faces arranged according to certain laws of symmetry. The studies of crystals made in the recent past have added to this conception also the idea of a necessary interior molecular structure and certain definite physical properties.

Thus, at the present time, there is no definite term to designate the more or less rounded or formless masses in which minerals occur, especially in rocks which yet possess the interior molecular structure and physical properties of crystals. For such spheroidal or formless masses the term *anhedron* (without planes) is proposed, and such mineral masses may also be spoken of as possessing an *anhedral* development.

(Other abstracts deferred to next number.)

THE

JOURNAL OF GEOLOGY

FEBRUARY-MARCH, 1896.

KAME AREAS IN WESTERN NEW YORK SOUTH OF IRONDEQUOIT AND SODUS BAYS.

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INTRODUCTION.

Scope of the paper.—The bays of Sodus and Irondequoit are the extreme points in the great bight or landward curve in the south shore of Lake Ontario. They occupy the lowest points of two north and south depressions in the land surface, the effect, probably, of northward preglacial drainage, and locate the embouchure of the buried ancient channels.

During the recession of the great ice-sheet, the drainage of the comparatively stagnant Ontario lobe seems to have been largely determined, in this region, by these depressions, which evidently received a large share of the glacial drift. The Warren waters which continuously laved the receding ice front assisted in distributing and leveling the detritus, while its successor, Lake Iroquois, completed the work at a lower level. The extensive silt plains between Sodus Bay and lakes Seneca and Cayuga, and the Irondequoit terraces, are examples of such lake action.

The purpose of this paper is not to discuss the complicated and interesting sequence of geologic events in the region under consideration, but to describe certain massive deposits of sand and gravel apparently formed by the glacial drainage.

The term "kame" is here used in the sense which has become generally accepted, as designating deposits, chiefly sand and gravel, having a knob-and-basin topography, and formed at the margin or periphery of the ice-sheet. The term "esker" (osar, serpent-kame) is employed to denote distinct ridges, chiefly gravel, believed to have been deposited in the beds of subglacial streams, being phenomena of the radial drainage.

Three of the kame areas here described have been mentioned in former writings,[1] but a new explanation of their character and relations is here given. The Junius area is thought to be here

[1] The Glacial Geology of the Irondequoit Region, Charles R. Dryer. Am. Geol. Vol. V., p. 202, April, 1890.

Eskers near Rochester, N. Y. Warren Upham, Proc. Roch. Acad. Science. Vol. II., p. 181, January, 1893.

The Kame-Moraine at Rochester, N. Y., H. L. Fairchild. Am. Geol., Vol. XVI., p. 39, July, 1895.

mentioned for the first time in print. The Rochester kame-moraine need not be redescribed.

A comparison of the deposits will be made, and an attempt to show the relation of the areas to the glacial drainage and the larger topography, with a brief discussion of the problems involved. (See map, Fig. 1.)

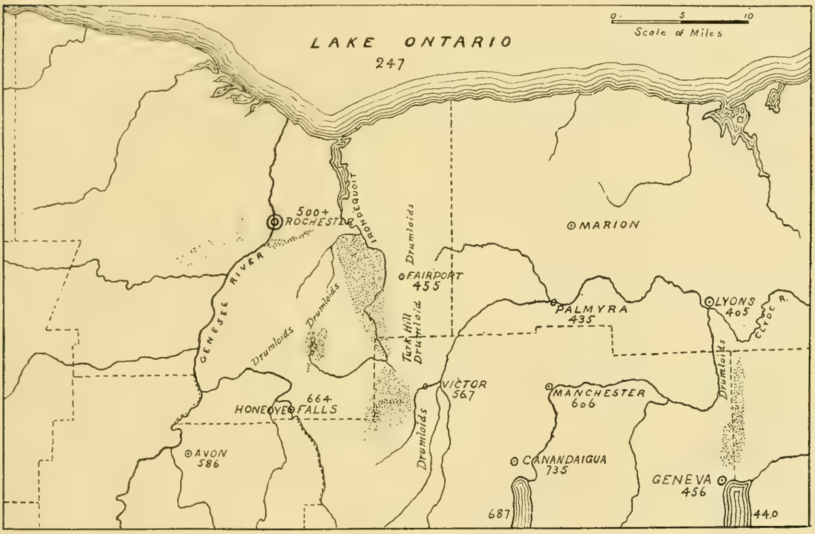

Fig. 1. General Map of Irondequoit-Sodus District.
Showing location of the four great kame areas. Figures indicate altitude above mean tide.

Distribution of water-laid drift.—Glacial sands and gravels are very generally distributed over western New York. Limited deposits of water-laid drift occur upon even the highest plateaus. It is a very common thing to find such deposits upon the summits or slopes of the drumloids, and some of the largest excavations of gravel for railroad ballast and other uses are superficial deposits associated with the drumloid or subglacial till. On low ground they are very abundant, but at altitudes under 875 feet above tide they are frequently leveled or distributed by the static waters or buried under lacustrine silts.

Very extensive deposits of water-worn drift occur in some of the larger stream valleys. In the upper Genesee valley immense deposits of stratified drift are mingled with the till, and much of it inextricably confused with the local lake sediments and subsequent stream detritus. South of the divide between the south-flowing and north-flowing waters the valleys are choked with the glacial wreckage converted into stream drift. Upon the north or Ontario side of the divide the glacial drift of all kinds has been retained and used, by the combined action of streams and glacial lakes, to fill depressions and thus give the smooth surface and arable soil of all the region between Syracuse and Buffalo.

Lesser kame areas.—To enumerate the smaller deposits of gravel or sand left in billowy or mound-and-basin topography would be tedious, even if it were possible. Those immediately about Rochester have already been described by the writer.[1] Other limited deposits occur in many places. Sometimes they are barely distinguished from the general drift sheet. Sometimes they are indicated by a few low mounds projecting from the sheet of lake or stream drift which has almost buried them. The limitation of such lesser areas is indefinite, as they blend into the prevailing sand or silt plains. At low levels, without close examination, dune sands may be mistaken for kame deposits.

One area, which merits fuller description than can now be given, is found north and south of Palmyra, Wayne county. This deposit is not large in amount of material or extensive in area but is interesting on account of the development of typical eskers. It consists of an irregular, broken series of kame mounds and esker ridges lying in the north and south valleys between heavy drumloids, and extending northward from near Manchester, Ontario county, past Palmyra to beyond Marion, a distance of about twelve miles. North of Palmyra and north of Marion are well-developed, typical eskers. At the southern end of the system, near Manchester, the sand deposit is more extensive.

[1] The Kame-Moraine at Rochester, N. Y., H. L. FAIRCHILD. Am. Geol., Vol. XVI., p. 39, July, 1895.

This drainage system does not seem to have been determined by any large north and south depression or other controlling topographic features, and it is likely that other slender series of kames and eskers may be found in neighboring drumloidal valleys.

IRONDEQUOIT KAME AREA.

Location and extent.—One of the most extensive kame areas in western New York occupies the valley of Irondequoit creek, stretching from the deep depression of the bay or gorge past Pittsford to Fishers in the northwest corner of Ontario county. The extreme northern point of the deposit lies in a bend south of Allen creek, west of the Irondequoit gorge, where the main line of the New York Central Railroad has a large cut and excavation in the sand, which at that point makes a broad, high mass. This portion of the sand area and the western edge as far south as Pittsford are shown on the Rochester sheet of the New York topographic map. From the sand cut to within two miles of Fairport the railroad traverses the northern part of the kame area, as it swings southeast and east around the Irondequoit gorge past Penfield station and across the creek, a distance in curvature of four and one-half miles. The Auburn division of the same railroad passes along the western edge of the area, while the Erie canal crosses the area and the Irondequoit creek on a high embankment in line with an esker, as described by Dr. Dryer.[1]

The entire length of the area from Allen creek to Fishers is about nine miles. At the head of the Irondequoit gorge the breadth is about three miles, the area being almost entirely upon the west of Irondequoit creek, or between that creek and its tributary, Allen creek. We have no means of determining how much of the northern end of the area has been removed by the excavation of the Irondequoit gorge. South to Pittsford the remnant of the kame area rapidly narrows, and is restricted to the western edge near Pittsford, as the greater breadth on the eastern side has been leveled by the waters of lake Iroquois

[1] Am. Geol., Vol. V., p. 203.

and subsequent stream action. From Pittsford southeast to Fishers the kame deposits fill the valley to a width of about two and one-half miles.

South of Fishers is the extensive mass of kame drift described below as the Victor kame area. It might be regarded as a part of the Irondequoit area, and certainly it belongs to the same drainage system. Being separated, however, by an interval of low ground and drumloid till at Fishers and being so different in topography, with so great mass, it is found appropriate and convenient to describe it separately.

Topography, altitude, and drainage.—The base of the kame area rises toward the south, about 100 feet between Penfield station and Fishers. The northern and lower portion lies near the level of the ancient lake Iroquois (435 to 440 feet in this region) and a considerable portion was beneath the waters. At Cartersville, one and one-half miles southeast of Pittsford, the highest detrital plain cut out of the kame deposit has an altitude of 435 feet, but a discrimination has not yet been made positively between the lake terraces and the subsequent stream plains. The altitudes upon the main line of the New York Central Railroad across the sand area near the head of the Irondequoit gorge are as follows: Crossing of Allen creek, 420 feet; in the deep sand cut, 423; Penfield station, 417; crossing of Irondequoit creek, 407; Fairport, 455. The top of the broad sand hill near Allen creek, cut by the railroad, has an altitude of about 470 feet. The canal has but one "level" across the Irondequoit valley, of 461 feet. At Fishers the Auburn branch of the New York Central Railroad has an altitude of 510 feet, which is, however, within fifteen or twenty feet of the creek level, in the eroded channel. The Lehigh Valley Railroad crosses the valley and the western plain, being at Victor 567 feet, Fishers 557 feet, Mendon, 572 feet.

The surface configuration of the kame area is varied and difficult to describe briefly. Most of the surface north of Pittsford is billowy, low mounds of fine sand, perhaps largely the result of wind action. At the canal crossing the sand hills are lofty, of strong knob and basin topography and surround two

lakelets. From here south the drift forms massive hills, which culminate two miles north of Fishers, opposite Railroad Mills flag station. The creek at this point is crowded to the extreme western edge of the valley by the drift hills, which stretch eastward two miles to the Turk hill drumloid mass. The higher hill on the western side, known as Woolston hill, has been truncated or leveled by lake waters somewhat under 700 feet altitude. The same level is conspicuously shown upon other hills, east and south. The surface configuration is very striking, being partly morainic and partly erosional.

The drainage of the whole area is northward by Irondequoit creek.

Eskers.—Lying in the midst of the kame sands, nearly opposite Cartersville and north of Bushnells Basin, is a conspicuous esker which has been briefly described by Dr. Dryer. This esker first appears in a field of Mr. D. L. Guernsey (lot 21 of Pittsford town map), which is a fine adhesive or silty sand with rare stones and broad basins and kettles. In the southward sloping field the esker emerges from beneath the clayey sand at its full altitude as a ridge of gravel. For a distance of about one-fourth of a mile it extends nearly southeast, parallel with the Palmyra road; then turning more to the south it suddenly ends at the crossing of two highways. This break is perhaps the result of erosion. Some sixty or eighty rods southeastward the ridge is abruptly resumed at a gravel pit. At the top the gravel is dirty and unassorted; in the middle section is a heavy bed of clear cobble; while the bottom is finer gravel but without much stratification. Two-thirds of the cobble up to six inches in diameter is Medina sandstone.

From here southward the esker ridge is very distinct, somewhat curving, with irregular crest line. It is mostly 30 to 40 feet high, with steep slopes, 26° to 30°, and the crest in some places is clear sand. The highest section is 80 feet above the basin at its foot, with an eastern slope of 34°, in coarse gravel. From the high section it curves southeast and is lost in the artificial high embankment of the canal at the creek crossing,

beyond which it is probably buried under the lofty sand hills south of the creek. However, it can probably be identified south of the canal, at the south end of the canal embankment, in a mass of cemented, dark red Medina gravel which is similar in appearance to an exposure in the esker at the north end of the embankment. About 30 feet in thickness is shown of this cemented gravel, of which, by estimate, from one-half to three-fourths is red Medina. This occurs at the canal level, 461 feet. Similar dark red, cemented gravels occur at other localities; one and one-half miles south near the Rand powder mill; at Fishers station; in the sand cut near Allen creek at the extreme north-west point of the preserved kame area; also near the bottom of the Irondequoit gorge. It is suggested that these masses of cemented Medina gravels found in the distinct esker ridge and at different points in excavations northward and southward indicate the deposit of subglacial streams deriving their burden chiefly from the Ontario excavation in the Medina, which esker deposits have been mostly buried under the later sands deposited in front of the retreating ice.

Lakes.—South of Bushnells basin two lakelets exist, locally called "Bullhead pond" and "Lily pond." They are about one-fourth of a mile apart. The "Lily pond" is said to be shallow, the other deeper and more surrounded by sand hills. These are somewhat below the canal altitude 461 feet.

Another lakelet called "Crossman pond," or "Cedar pond," lies one-fourth mile north of Woolston hill, by the side of the Ketchum road. It has an area of about two acres, with a reported depth of 60 feet. The altitude is about 520 feet (aneroid).

Between Pittsford and Penfield are at least five pools and one swamp, lying in depressions in the billowy sand.

Composition and structure.—The surface of the northern portion of the area is chiefly a fine yellow sand. Below the Iroquois level this sand is much affected by the winds, and the billowy surface may be wholly due to æolian action.

The cutting by the railroad near Allen creek exposes about 70 feet of sand, inclosing a few lenses of gravel, and some angu-

lar material. A few bowlders occur, mainly Niagara. On the north side of the cut, twenty feet from the top, are heavy masses of cemented Medina gravel, about ten feet thick. These do not seem continuous. Another mass of similar gravel appears at the bottom of the excavation.

The top of the high mass is mostly fine sand but containing angular stones and a few bowlders. The surface from here south to Pittsford, two miles, and east to Penfield, one and one-half miles, is thrown into domes and basins. No gravels appear upon the surface north of the esker described above, although gravel is said to underlie the sand.

At Bushnells Basin and the canal crossing of Irondequoit creek the high hills are mainly the fine yellow sand, but heavy beds of gravel are worked near the canal, and cemented Medina gravels occur as described above.

The summit of the leveled Woolston hill is gravel, and heavy gravel is exposed in gullies on the slope. The hills of this culminating mass are reported as largely sand.

Till occurs in the base of the Woolston group, and on a terrace corresponding nearly with the plain stretching westward toward the Mendon hills. A land slide exposes 30 feet of till on this level, which is towards 100 feet above the creek, with a great thickness of sand beneath it. Till also occurs at a higher level on the north side of the Woolston hill. A conspicuous hill south of village of Fishers and another smaller one southeast are true drumlins.

The depth of the sand upon the borders of the northern part of the area cannot be great. Toward Penfield the water pools indicate a substratum of rock or till at altitude of about the Iroquois level. Through the midst of the area there exists a buried ancient valley.

Surrounding features.—The kame deposit lies upon the glacial filling of the ancient valley, lapping upon the drumloid till either side. Being wholly in a north-sloping valley and at a low altitude, the lowest northern part of the deposit was at first leveled by the waters of lake Iroquois, while the whole area has been

subjected to the valley drainage. Doubtless a considerable part of the original mass has been swept into the Irondequoit bay depression. The details of this history, as connected with Irondequoit bay, will be reserved for another paper.

There are no important morainal features upon either side of the kame area. West of the southern part of the area, at a distance of five miles, is the large, isolated group of the Mendon kame hills, with a plain intervening; otherwise the east and the west boundaries are drumloid. South is the enormous deposit of gravel forming the Hopper and Fort hill groups of Victor, which are really the antecedent part of the Irondequoit kame system. At Victor is a break in the Turk hill drumloid range, through which the Lehigh Valley and the Central railroads find passage.

VICTOR KAME AREA.

Location and extent.—The most massive kame hills in the region, and probably in all western New York, are in the southwestern part of the town of Victor, Ontario county, extending into the towns of East and West Bloomfield and into the southeast corner of Mendon, Monroe county. (See Fig. 2.) They cover an area of some ten square miles and attain in the "Hopper" hills the lofty altitude of over 1100 feet. The area is elongated north and south, the northern apex being at Fishers station the Auburn branch of the New York Central Railroad, and the southern end forming a narrow belt terminating two miles south of Millers Corners station, on the Batavia and Canandaigua branch of the same railroad. The total length is about seven miles. The greatest breadth is about three miles, where the group culminates in the remarkably bold ridges northeast of Millers Corners.

Topography, altitude and drainage.—The higher kame hills of this area have a very remarkable topographic relief. The culminating mass is locally known as the "Hopper" hills, which lie immediately north and northeast of Millers Corners, upon the north and south line between Monroe and Ontario counties. This is a lofty, ridge-like mass lifted high above the surrounding

kames and conspicuous over a wide territory. (See Fig. 3.) The mass is irregular in form, but with the longer axis north and south, or east of south, and a length of over one mile. Upon all sides

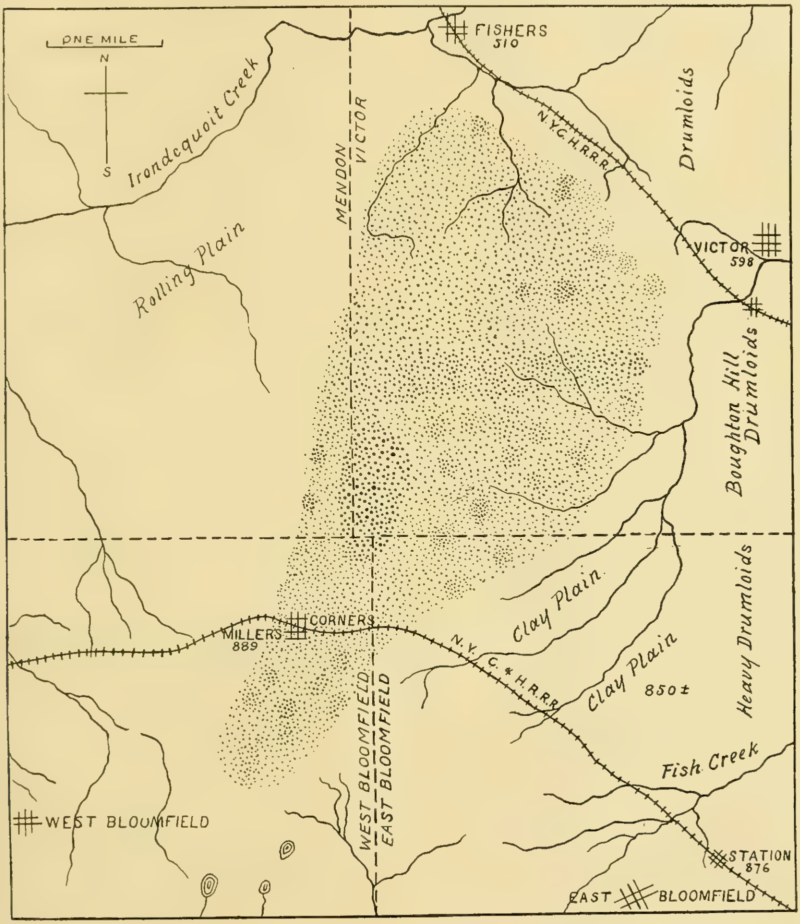

Fig. 2. Map of Victor Kame Area.
Figures indicate altitude above mean tide.

except the south it rises steeply 400 feet, attaining an altitude of 1131 feet (aneroid) above sea level, overtopping everything in western New York north of the Devonian plateau. Superficially the

mass is entirely water-laid drift, mainly gravel, and there is slight evidence of clay or till. No deep exposures have been made, and there are no land-slides, as occur upon neighboring steep kames where clay exists. The people in the vicinity report no clay or "heavy soil." The cultivated fields upon the summit show only sand and rather fine, well-rounded gravel. However it is possible that the water-laid drift is only a veneer upon a mass of till.

Southward the Hopper mass is continued in the belt of kame hills of lesser height stretching past Millers Corners. These have an altitude of 900 to 1000 feet, which height is preserved until they terminate against the rising ground to the south.

With only a fringe of comparatively low knolls, the western slope of the Hopper range falls rapidly to the rolling clay plain which declines westward toward Mendon and Honeoye Falls.

Upon the north and northeast a narrow gulf separates the mass from the western end of the Fort hill kame range. East and southeast a narrow valley intervenes between the Hopper range and the lower kames. The latter have an average altitude of 850 to 900 feet, being mostly water-leveled, and blend into a a till or clay plain of the same altitude, flanking the heavy drumloid ridges eastward. These drumloids are in line south from Victor, the northern one being known as "Boughton" hill.

North of the Hopper range and separated by a narrow valley is a broad, less elevated series which we will name the "Fort" hill range. This name is locally given to the conspicuous, abrupt plateau at the eastern end of the range, about two miles from Victor, which is historically famous as the site of a stronghold and of the defeat of the Seneca Indians by Denonville, in 1687. This range has been mostly truncated by static waters, the plateaus being 850–865 feet altitude and the highest summit 885 feet (aneroid). The breadth is about one-half mile and the length about two miles. The trend is north of west, the western end being separated from the northern end of the Hopper range by only a narrow gulf.

Northward toward Fishers the hills seem small by comparison

with the Hopper and Fort hill ranges, but are really of respectable size, somewhat mound-like and billowy in contour, closely huddled together, and diminishing toward the northern end of the area.

The surface of the entire area is knob and basin topography. Broad basins and deep kettles occur even to near the top of the

Fig. 3. VICTOR KAMES.

View from near Tobin's Corners, looking west 15° north, "Hopper" Hills in background. The point of view is upon the upper erosion plane of Warren waters, which also shows in distance upon right.

Hopper range. This topography has lost, however, some expression by the leveling effect of the Warren waters. Between 850 and 875 feet altitude the kames are strongly terraced or truncated, this plane being one of the conspicuous features of the region. A few summits in the southeastern part of the area, and one summit of the Fort hill range, have escaped the leveling action of

the static water. Another water-plane, toward 700 feet altitude, is less evident.

The drainage is west and north into Irondequoit creek and north by Great brook, the latter flowing upon the west side of the Boughton drumloid and joining Mud creek east of Victor.

Few water-pools worth mentioning occur. One pool lies in a deep basin between the western ends of the Hopper and Fort Hill ranges, back of the house of Mr. Covill. The large basins seem to be of pervious materials and far above the till or rock floor. Good kettles holding water except in dry seasons occur north of the Fort hill range.

Eskers probably do not occur in this area. If any exist they are in the northern part of the area east of the Fishers and Millers Corners road.

Composition and structure.—Till is found in the knolls near Millers Corners. The top of one hill, a mile northeast and with altitude of about 900 feet, seems to be wholly till, with bowlders. One-fourth mile west of the station the railroad makes a cutting in till which is probably drumloidal. Some of the slopes and summits are coarse sand, but the great bulk of the higher ranges is gravel. Fort hill is capped with sand, but the rest of the range is mostly gravel. Less sand is seen upon the summit of the Hopper range, the highest points being fine gravel. The composition of this range has been described above. The hills south of Millers Corners contain much gravel and some heavy beds of very round cobble. The bulk of the northern, constricted area toward Fishers seems to be sand, but Dr. Dryer states that there is much till in the knolls and plateau lying north of the Fort hill range.

Stones and cobbles are found in the sand at various elevations. The foundation of the southern part of the area is Corniferous limestone and the characteristic chert is found upon the summits of the Hopper range. The northern edge of the Corniferous is traced near Victor.[1] Large bowlders of crystallines, Medina and Corniferous are seen along the highway between

[1] Economic and Geologic Map of the State of New York, by F. J. H. Merrill, 1895.

Fishers and Millers Corners, especially near Millers Corners. A large proportion of the gravel, even to the Hopper summits, is Medina.

Surrounding features.—This kame area evidently belongs to the same glacial drainage as the Irondequoit kame area. The reasons for treating it as a separate area have been given above.

The area is bounded on the northeast by the northwest-southeast valley reaching from Fishers to Victor. Upon the east it is bounded by the Boughton hill drumloid which runs directly south from Victor village and which, notwithstanding the break at Victor, may be regarded as the southern continuation of the Turk hill mass, with which it is in line. Southeastward the kames are lost in a smooth plain of till or clay, as mentioned above, which joins a marsh north of East Bloomfield and is the level of the upper erosion plane of Warren waters. As casually seen in exposure by the roadside, this clay is of reddish color, with only small but striated stones. The streams have excavated narrow channels 40 to 60 feet deep through this plain, and are possibly on rock. Southward is high ground with a drumloidal surface, the northern spurs of the Devonian plateau.

Westward is a low silt plain, evidently deposited as a lake floor, and which may be regarded as an overwash from both the Victor and Irondequoit kames. This plain declines west toward the Honeoye creek and north toward the Irondequoit creek, with an altitude averaging about 600 feet.

It will thus be seen that the Victor kame area lies in an angle or embayment of the Warren shore line, opening toward the northwest. Northwest a few isolated mounds of sand rise out of the low silt plain, the only phenomena connecting this kame area with the Mendon kame area. Neither westward nor eastward are there any good evidences of morainal till.

In Professor Chamberlin's description of the terminal moraine in New York[1] this Victor kame group was united with the southern part of the Turk hill mass and regarded as an intermediate

[1] THOMAS C. CHAMBERLIN, Terminal Moraine of the Second Glacial Epoch. Third Ann. Rep. U. S. Geol. Surv., p. 353, and Plate XXXIII.

or interlobate moraine. The same view was subsequently held by Dr. Dryer.[1]

By referring to Professor Chamberlin's description it will be seen that he had serious doubt as to the correctness of the diagnosis. He closes the brief description with the following: ". . . . for the glacial movements on either side of the moraine appear to have been southerly, as judged from the prevalent trend of adjacent drift ridges, and therefore essentially parallel to the moraine, instead of being at right angles to it, as in the case of a true intermediate moraine."

The Turk hill body of drift is somewhat anomalous but is surely drumloidal in general character. The northern end, at Fairport, is divided into a few large ridges, which blend together southward and constitute a broad, plateau-like mass, over 900 feet in altitude. The western boundary is a fairly continuous slope, with considerable water-laid drift banked against it, and the Irondequoit kame area flanking it opposite Fishers. The eastern side is more irregular and the depressions have been largely filled with water drift. The southern declining half of the drift body is also very gravelly and of irregular surface. East of the high mass the drumloids are numerous but smaller. Much of the morainic appearance on the slopes and on the southern half of the Turk hill mass is certainly due to sub-aërial erosion. The drainage is all free. There are said to be no lakes, no swamps, and no sinks or kettles.

Upon Professor Chamberlin's map (Plate XXXIII. of the paper referred to) this supposed moraine is isolated, and with its north and south trend is quite inexplicable. It is the only isolated moraine depicted in New York north of the great east-and-west terminal moraine, and its elimination from the map simplifies the glacial phenomena of the region.

MENDON KAME AREA.

Location and extent.—A remarkable accumulation of kame sands and gravel occurs in the southeastern part of Monroe

[1] See former reference.

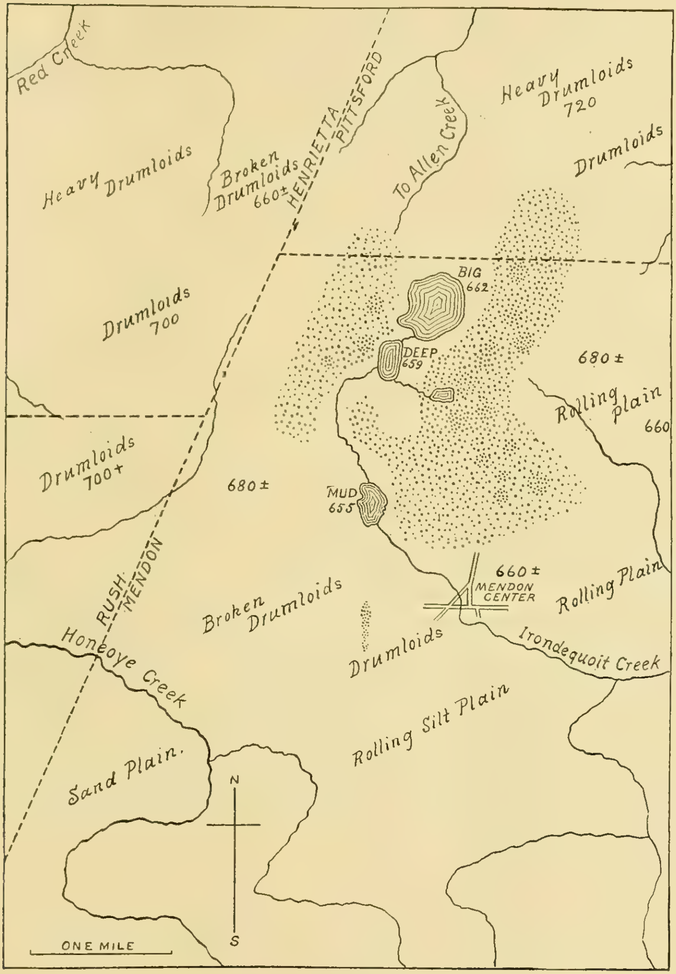

Fig. 4. Map of Mendon Kame Area.
Figures indicate altitude above mean tide.

county in the town of Mendon. The deposit has been referred to in the papers by the writer and by Dr. Dryer, but they deserve a fuller description.

The hills which constitute the heart of the kame area lie either side of the Mendon ponds. They may be said to form two

series of hills and knolls having a general direction of S. 30° W. with a low valley between holding the five ponds. (See Fig. 4.) The heavier group lies on the east side of the valley, extending between two north and south roads a distance of about two and one-half miles, with a breadth of three-fourths of a mile. The western group lies between the ponds and a north and south road and is only about one-third the area of the eastern group. The southern limits are not definite but shade into the silt-covered drumloids.

Southward, past Mendon Center, the general contour of the surface is drumloidal, but there seems to be a deposit of silt or sand over the surface and filling the hollows. This area of silt is indefinite and is intersected by the excavation of the Honeoye creek valley. Beyond this excavation a sand plain forms a conspicuous level, locally known as the "Mendon plains." This lies southwest of Rochester Junction on the Lehigh Valley Railroad and extends to Sheldon Corners.

Eskers.—Through the midst of the eastern high track there winds an esker ridge. This is not conspicuous, but from some points of view the knolls blend so as to form a very evident eskerine. (See Fig. 5.)

One mile south of the kame area occurs a singular group of knolls that must be regarded as an esker. This lies one-half mile south of Mud pond and three-fourths of a mile west of Mendon Center. The north end of the esker is cut by the east and west highway. This esker consists of four connected knolls, in a north and south line, making altogether a length of about one-eighth of a mile. The local name of the knolls is the "Dumpling hills." The summits and slopes of the ridge and the road cutting show only a fine, stiff or silty sand, similar to much of the surface of the region southward. A few stones were observed in the sand. The esker is thirty to fifty feet high but surmounting a ridge, probably drumloid, it is conspicuous over considerable area. Its altitude is 762 feet (aneroid). The sides of the esker are very steep and ridges of sand stretch away from it at right angles.

Topography, altitude and drainage.—The Rochester sheet of the New York topographic map includes the kame area, in twenty-foot contours, and to this map the writer is indebted for the altitudes. The swamp area surrounding the ponds has an altitude at the north end of 665 feet and at the south end of 655 feet. The highest peaks of the kame hills, in the eastern tract, are

Fig. 5. MENDON KAMES.
View looking southwest over "Harris" lake. Eskerine at right.

given contours of 840 feet. These are 100 feet higher than the highest drumloids in the surrounding region. This altitude of the sand hills is a striking feature. Eight miles southeast are the Victor kame hills of much greater height. Higher ground is found in about ten miles southward on the Hamilton-Chemung plateau. North of this plateau of the "Finger lakes" region there is in all of western New York only one area, excepting the Victor hills, surpassing in height the Mendon hills; this is the drumloid mass of the Turk hill group, seven miles east,

which is about eighty feet higher. The most northern point of the high plateau is at Batavia, on nearly the same parallel as the Mud pond, where the drumloidal and morainic drift capping is something over 900 feet.

While the summits of the kame hills are 100 feet above the surrounding drumloids the enclosed swamp valley is nearly 100 feet lower than the drumloid region. It has not been determined whether the swamp is floored by rock or by impervious drift.

The topography of the hills is of pronounced knob and basin type and strikingly in contrast with the neighboring drumloids. (See Fig. 6.) They are conical, mammillary, billowy, enclosing numerous basins and deep kettles. The hills have nearly escaped the leveling action of the Warren waters, the summits lying between the two erosion planes. However, the lower, 700 feet, plane shows upon the western hills.

The drainage from the ponds and enclosed valley is immediately southward, forming the head of the Irondequoit creek. After passing Mendon Center the stream swings eastward to Fishers and then northward to Irondequoit bay. From the borders of the kame area the drainage is radial in all directions.

The altitude of the southern part of the overwash sand and silt is about 600 to 610 feet (aneroid).

Lakes.—The location, drainage and relative size of the four lakes are shown in the accompanying sketch. The "Big pond" lying most northerly and the head of drainage, has an area of about 100 acres, and a depth of only about eight feet. The "Harris pond" lies nearly surrounded by the heavy drift on the east side of the valley. It is only a few acres in extent but is said to have a depth of twenty-four feet. "Deep pond" is mostly shallow but is said to be thirty-four feet at the deepest place. "Big pond" and "Mud pond" are shallow. The margins of the lakes are mostly swampy, but much of the valley bottom between the lakes is tilled land.

Composition and structure.—The kame hills are mostly pasture land or under cultivation. Very few exposures have been made

and these show mainly imperfectly assorted gravels. The tops and slopes of the hills are frequently of material so fine and adhesive as to be clayey. Till is found in the high knolls north and south of the Harris pond and probably occurs elsewhere. In the valley near the Deep pond lies one small but very distinct elongated drumlin. No exposures are seen of fine, clear sand

Fig. 6. MENDON KAMES.
View looking west of north over "Big" and "Deep" lakes.

blown about by the winds as in the Irondequoit and Junius areas and other sand areas near Rochester. The materials as a whole are varied, but the finer are generally rather adhesive or silty.

Some gravel pits in the borders of kame area show materials one-half Medina. Large bowlders of crystalline rock and rarer blocks of Niagara limestone occur throughout the region. In the middle valley and upon the southern borders of the area frequent cobblestone fences, one-half Medina, indicate considerable

coarse material upon the surface. Two huge Niagara blocks were seen on a gravel knoll at an altitude of 720 feet. A well upon one of the knolls in the southern part of the eastern section is said to have penetrated 130 (?) feet of clear sand.

Relationship to surrounding features.—An examination of the Rochester sheet of the New York topographic map will give a general view of the surface and surroundings of the kame area. It should first be noted that it lies in a drumloid area of high altitude, and a trifle west of south of the Irondequoit bay depression. The tract northward between the kame hills and Pittsford, four miles, is strongly drumloidal. Upon the west the country is distinctly but brokenly drumloidal and for two miles is not so strongly ridged. The twenty-foot contours of the topographic map do not anywhere fully indicate the drumloidal character of the surface. Southwestward the surface is drumloidal to the Corniferous escarpment, the overwash partially burying the lesser inequalities. Immediately south of the kame hills, at the village of Mendon Center, are distinct drumloids, and others apparently occur upon the southeast border. Eastward and southeastward the country is comparatively open and rolling for several miles, to the Victor kame hills. Immediately east of the middle of the kame area the ridges are quite wanting, the highest contour being 680 feet.

Concerning the rock floor or base of the region little is known. Upon the Howard farm, on the extreme western edge of the kame area, it is said that a well, starting on the 700-foot contour, was driven 130 or 140 feet without reaching bed rock. The well above referred to started at an altitude of about 680 feet and found no rock at depth considerably over 100 feet. In the southern part of the sand plains, on the farm of Mr. Judson F. Sheldon, rock is said to have been found at a depth of 69 feet. The plain at this point is near 600 feet altitude.

Eastward or westward of the kame hills there is but the slightest suggestion of a moraine. One and one-half miles northward of the Big pond a slightly morainic surface is shown among the drumloids, also two miles west, along the Lehigh Valley Railroad.

JUNIUS KAME AREA.

Location and extent.—A large and interesting kame area is

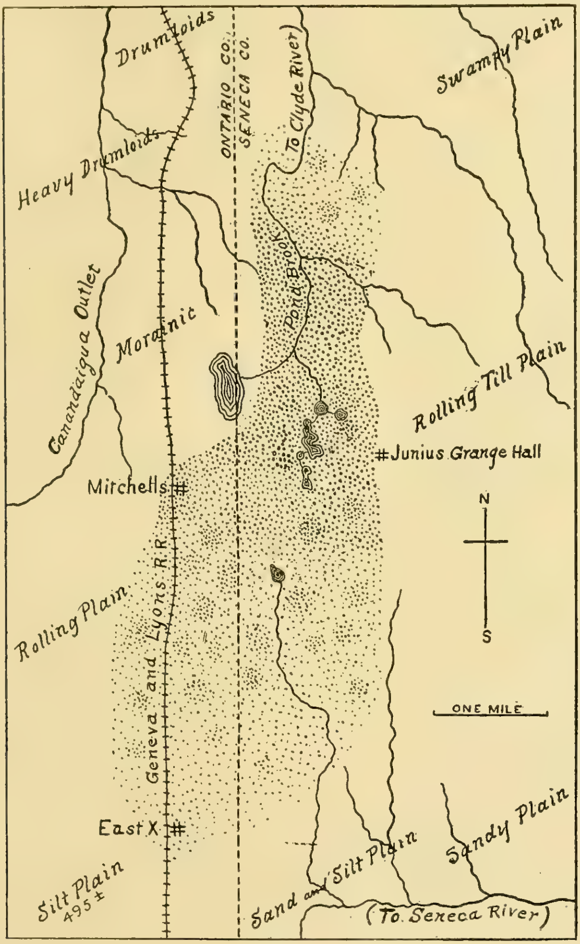

Fig. 7. MAP OF JUNIUS KAME AREA.
Figures indicate altitude above mean tide.

found north of Seneca lake in the town of Junius, in the north western edge of Seneca county and extending over the line into the town of Phelps, Ontario county. (See Fig. 7.) It lies mid-

way between Geneva and Lyons, but east of the meridian line, and constitutes the highest ground upon its meridian between lakes Ontario and Seneca. The boundaries of the sand areas are indefinite but the northern limit seems to be about one-half mile north of Bisch's sawmill or five miles in a direct line from Lyons. The heart of the area is the group of knolls surrounding the Junius ponds. Southward the knolly area broadens, east and west, and blends into the wide silt plain which extends to Seneca lake.

The width of the kame area on the "state road," which passes between the ponds and through the heart of the area, is about one and one-half miles. Junius Grange Hall is just at the eastern limit of the sand, and the western limit is beyond Mitchell's station (West Junius P. O.) on the Geneva and Lyons R. R. North from this station the railroad passes a mile west of the sand area; southward the railroad lies in the sand to beyond East X station, within three miles of Geneva. The length from Bisch's Mill to East X is about six miles.

Topography, altitude and drainage.—It is said that the surveys for the Geneva and Lyons Railroad made the height of the South pond 34 feet above Seneca lake. This is probably not far from correct, and would make the altitude 474 feet above tide. The South pond is about 13 feet higher than the other ponds. All the ponds in the heart of the area are drained northward by one brook into the Clyde river, with a fall of about 80 feet. The southern part of the area, including the swamp and the Lynch pond, is drained southward into Seneca river.

The topographic relief of the kame area is not remarkable. The higher knolls rise some 70 or 80 feet above the ponds, giving an extreme altitude of perhaps 550 feet above tide. The surface in the region of the ponds is decidedly hilly, but southward it would be better described as "billowy."

Lakes.—The lakes are notable for their reported depth as compared with their small area. The largest one, "North pond," with an area of about twenty acres, is said to be 62 feet deep. The others are reported to be of great depth. "South pond,"

the head of drainage, has a surface of about nine acres. The smallest, lying between North and South ponds, has an expanse of less than an acre. The two lakelets furthest north are called "Newton ponds." Only five lakes are here recognized, although the group is sometimes called the "Seven ponds." "Burnett's pond," which lies west of the sand area and is much larger and more shallow, is not here regarded as a member of the kame group. About one mile south is another lakelet in a large swamp.

The five kame ponds are said to retain their level in the driest seasons. Without any surface stream supply they must derive their waters from a large basin of sands enclosed in impervious drift.

Composition and structure.—The exposed material of the kame area is mainly fine yellow sand. A few gravel exposures are met with in the neighborhood of the ponds. East of Mr. J. C. Vandemark's residence a dark cemented gravel occurs in the crest of a knoll. The matrix is a dark, reddish, coarse sand. Of the gravel not over one-quarter is Medina, the remainder being a mixture of many hard rocks from the northern terranes. Some clay or stiff soil is said to occur on the tops of the knolls. Stones and bowlders are found at all heights in the sands. Southeast toward Waterloo and south toward Geneva the billowy yellow sands terminate in the silts of a broad plain, with occasional low, sandy knolls.

Surrounding features.—East and south of the kame area is the somewhat lower silt plain which extends from Geneva and Waterloo northward past Clyde to Sodus bay. The surface of the ground bordering north and west is boldly drumloidal, but northward it is slightly lower in altitude. West of the north end and heart of the kame area is a significant morainic deposit. It is best described as a morainic filling of the north and south valleys between the drumloid ridges. Part of the irregularity may be due to the east and west outcrops of harder strata of the upper Salina. This morainic surface extends along the Geneva and Lyons highway from about one mile south of Alloway to West

Junius post office (Mitchell's station). It is regarded as marking the edge of the ice-sheet during the accumulation of the larger kame hills by the concentrated drainage.

COMPARISON OF THE KAME AREAS.

It will be instructive to briefly compare the principal features of the four large areas described above, including in this comparison the Rochester kame-moraine and some lesser areas.

The Irondequoit, Victor and Mendon areas are apparently the result of heavy drainage from the wasting ice-sheet, concentrated along the Irondequoit depression. The neighboring deposits of the Rochester kame-moraine and other lesser deposits southwest and west of Rochester have an uncertain, if any, relation to the Irondequoit drainage. The Junius area is in a separate and distinct glacial drainage system, belonging to the Sodus depression.

The Irondequoit area is singular in one respect; it rests in the lowest channel of the depression and partly below the level of Iroquois waters. The other areas are upon relatively high ground and constitute the highest points of land in their vicinities and upon their respective meridians, north of the Devonian plateau.

All the areas are alike in being located in the basin of lake Warren. Excepting the Junius area they are also alike in bearing evidence in the beautifully terraced and truncated sand hills of their accumulation beneath the Warren waters. Two strongly developed water levels are conspicuous; the higher between 850 and 900 feet, the lower about 700 feet above tide. The Junius area lies at so low an altitude that the hills have escaped the leveling action of any long pause of the Warren waters, their summits being much below 600 feet.

The areas are alike in having an overwash sand or silt plain to the southward.

The basement terranes are as follows: The Rochester kame-moraine lies upon the southern edge of the Niagara limestone. The Irondequoit stretches across the whole breadth of the Salina. The Mendon and Junius areas lie upon the Salina but near its southern limit. The Victor area lies chiefly upon the Corniferous

limestone. The composition of the three southernmost areas seems to partake somewhat of the clayey nature of the Salina strata. The Mendon, the Victor, and the Irondequoit sands, above the Iroquois level, are generally more coherent and argillaceous than the lighter sands of the Pinnacle and Chili hills near Rochester. This, however, may not be of great importance, especially since the Junius sands are also comparatively light.

The four areas lie in the midst of drumloid ridges which certainly antedate the kame deposits that partially overlie them.

Only the Rochester area has any clear connection with an extended frontal moraine. The morainic surface immediately west of the Junius hills is significant but not sufficiently clear or extensive to be important in this connection. It should be said, however, that in the drumloidal region bordering these kames an amount of morainal material even surpassing that in the moraine west of Rochester would scarcely be noticeable.

The break at Fishers may possibly be partly the scouring effects of currents during the lowering of lake Warren, but not entirely, and the cessation at this point of the process of such heavy drainage accumulation would seem to render probable the accumulation at some other point on the ice-front, east or west. For this reason the suggestion is made that the Mendon area may have been formed by the temporary westward diversion of the main Irondequoit drainage; that is, the Mendon water deposits may represent the gap between the Victor and the Irondequoit deposits. The center of the Mendon area is about five miles from Fishers, which lies in the break between the other two areas, and it has the proper position transversely to the drainage line.

DISCUSSION OF PROBLEMS.

The precise manner of formation of the kame hills is the most obtrusive question. Two elements may be considered in this connection, the composition of the kames, and their altitude and location. In composition the red Medina waste plays the

conspicuous rôle. In the Irondequoit esker it is 50 to 75 per cent. of the whole mass. The kames contain somewhat less waste of the Medina, although the red color is usually pronounced even upon the highest summits. The Medina is the lowest terrane of the region, the top being only about 100 feet above Lake Ontario. In the Victor subaqueous kames, leaving the lofty Hopper range out of account, Medina gravel has been lifted towards 500 feet. Of this height not over 200 feet is due to the southward rise of the rock base, which leaves nearly 300 feet of actual lifting of the gravel. The distance from the Victor hills to the nearest Medina exposure, at the head of the Irondequoit gorge, is 12 miles. Another example is more striking. The Corniferous chert also occurs upon the tops of the Victor hills. The limestone is supposed to underlie the hills, but it cannot extend farther north at present than three or four miles. Within that distance the Corniferous has been lifted about 300 feet. Flotation by ice in lake waters might explain the presence of fragments of chert on these summits, but the Medina gravel which forms a constituent part of the hill summits cannot be so accounted for. The overriding of the gravel deposits by the readvancing ice will probably account for the till upon the higher kame summits, as it will for the angular blocks of Niagara limestone upon the summit of the Pinnacle, and for the till on Cobb's hill of the Rochester kame-moraine, but the areas here described give no evidence of extensive burial under glacial ice.

The summits of the Hopper ridge are about 250 feet above the upper lake terraces. It seems possible that some part of this remarkable elevation of the water drift upon this ridge may be due to a pushing by the ice in a slight readvance. The direction and form of this high ridge, however, are not entirely consonant with its being a pushed moraine. The interior structure of the hills is unknown. This explanation, a pushing by the ice, applies in part to the Rochester kame-moraine. Possibly it may partially apply in the case of the Fort hill range lying immediately north of the Hopper range, but it would

scarcely be suggested by the form of the hills in either of the other kame areas. It should be noted here that the directions of the Hopper and Fort hill ranges are nearly at right angles to each other.

There can be no doubt that the greater part of the material of all the groups has been derived from the Ontario excavation and rock degradation upon the north, and has been carried southward up hill. It has been lifted hundreds of feet by either ice or water, or both combined. Upward currents probably do not exist in the body of the ice-sheet sufficient to lift the subglacial débris to such a height in so short a distance. Indeed, the material, if taken from the ground moraine, would require to be lifted far above its present height, as the fully rounded gravel and the large proportion of sand represent the wear of a considerable journey by stream transportation.

The theory advanced by Professor Shaler[1] several years ago seems the most acceptable. In some manner the lifting of the gravel and sands may have been done by forceful upward currents of water at the ice-front, impelled by the hydraulic pressure of water in the lofty ice-sheet to the northward. The kame deposits under discussion were doubtless formed in the waters of lake Warren, along a belt where the deep static waters opposed the detritus-burdened, glacial torrents. The buoyant effort of the static water probably kept the ice-front comparatively steep or high. The heavier glacial streams would probably cause deep reëntrant angles in the ice-front, or even canon-like indentations, which would be choked by the piling of the detritus until a balance was established between the height of the detrital dam and the lifting power of the stream. The full analysis of the interaction of the three agencies, the ice-sheet, the subglacial streams, and the static water, would be exceedingly instructive in this study.

Professor Shaler supposed the Martha's Vineyard kames to

[1] On the Origin of Kames. Proc. Boston Soc. Nat. Hist. Vol. XXIII., 1884, pp. 36-44. Geology of Martha's Vineyard. Seventh Ann. Rep. U. S. Geol. Sur., 1885–6, pp. 314–322.

have been formed beneath sea-water. The static water in the cases under discussion was fresh water and would oppose less resistance to the glacial streams.

The chief and perhaps fatal objection to this explanation is the extreme height of the Hopper range, which is 250 feet over the highest water-level, but there is so much uncertainty concerning the internal composition of the Hopper mass that it is an unsafe basis in this argument.

This discussion has a direct bearing upon the matter of glacial drainage in another aspect. To deny the possibility of ice-dams, or the capacity of glacial ice to serve as a barrier to deep water, requires evidently interglacial or subglacial drainage to the sea in the case of the Ontario glacier. The topography of the land surface is such that during the melting toward the northeast of the Adirondack-Ontario ice-sheet the resulting waters must either have been ponded in front of the ice or have been suffered to escape beneath the ice to the sea by the St. Lawrence or the Mohawk depressions. The latter alternative means northward drainage. As a matter of evident fact these kame areas consist of matter derived from terranes lying upon the north, and as evidently were produced by water currents from the north. The waters flowed from the ice-sheet not into the ice-sheet.

The fact of static waters over the region is clearly shown by the two conspicuous erosion planes upon the kame hills, as already described. The suggestion of marine submergence is not entertained.

The general trend of the kame areas southwestward may have been due to the prevailing direction of the glacial movement.

The glacial débris above the ground moraine throughout this region seems to have been deposited chiefly as water-laid drift. The kame areas stand apart, without morainic connections, and terminal or frontal till moraines are no more than barely observable. The causation is probably complex. Rapid ice retreat; action of the lake waters preventing considerable local accumu-

lations of morainal till, or subsequently either dispersing or burying them; and the fact of the heavy glacial drainage, occur to mind as possible causes. Another important fact is that the bulk of the ground moraine had been left as heavy drumloid ridges.

The relation of the drumloid and the kame deposits are such as to clearly indicate the later deposition of the kames. For many reasons the writer has no doubt of the subglacial origin of the drumlins and drumloids of western New York, which are here regarded as a part of the ground moraine.

H. L. FAIRCHILD.

A PRE-TERTIARY NEPHELINE-BEARING ROCK.

While engaged in a petrographical study of the glacial drift bowlders in the neighborhood of Columbus, Ohio, with a view to ascertaining their possible source, a bowlder of unusual interest was noted. It is related to types which have only recently been described in this country. The rarity and interest of the type and the hope of making possible its future identification with an occurrence found in place seems to justify a special description of this bowlder. Only a single specimen was found. This was about a foot and a half in diameter, with a surface weathering conspicuously rough and brown.

Macroscopical characters.—On the fresh fracture the rock shows a dark gray, compact, aphanitic groundmass, thickly studded with lath-shaped or, more rarely, tabular crystals of a triclinic feldspar. These phenocrysts have an average length of half an inch, but may be more than twice that length. They are white to colorless and translucent, with a pearly luster, and show the striations due to polysynthetic twinning, Upon the weathered surface of the rock they stand out in marked relief and are an opaque white, with a chalky texture.

Less conspicuous, but distributed in great abundance through the rock, are groups of broadly rectangular, or hexagonal, white or nearly colorless crystals. These crystals do not exceed two millimeters in diameter and are uniformly and clearly distinguished from the feldspar by their shape and size. They are not in marked relief on the weathered surface, but are conspicuous as small, squarish, chalky white spots.

A dark-colored, ferromagnesian constituent, presumably augite, is present less conspicuously, as a phenocryst. Magnetite can also be detected, and doubtfully olivine.

Microscopical characters.—The microscope shows the essential

constituents of the rock to be plagioclase, nepheline, augite and hornblende. As accessory constituents, always present in some amount, are olivine biotite, apatite and magnetite. As secondary constituents are a zeolite, muscovite, kaolin, calcite and uralite. The rock is comparatively fresh and possesses a pan-idiomorphic holocrystalline structure. Secondary structures due to pressure are not manifest.

Plagioclase.—The feldspar is fresh, idiomorphic and polysynthetically twinned. The twinning lamellæ are indistinct and irregular. It is comparatively free from inclusions which, when present, are apatite, augite and hornblende crystals and microlites. Some of the feldspar was isolated and its specific gravity tested by the Thoulet solution. It proved to be 2.642 indicating a variety of the oligoclase-albite series. Feldspar of the second generation occurs in the groundmass, of which it constitutes the major part. It is broadly lath-shaped and does not show repeated twinning, but is, in many instances, twinned according to the Carlsbad law. Besides occurring in lath-shaped crystals it acts as a cementing material for the minerals of the groundmass. The presence of muscovite is conspicuous as an alteration product. This alteration product, the high alkali percentage of the groundmass and the optical properties, indicate that the feldspar of the groundmass belongs at the more acid end of the series, probably orthoclase in part.

Nepheline.—The groups of colorless, broadly prismatic or hexagonal crystals observed in the hand specimen prove to be nepheline. The hexagonal sections show the broad uniaxial cross and negative double-refraction of nepheline. The prismatic sections show parallel extinction, a weak double refraction, and two rectangular cleavages. The crystals contain as inclusions apatite and augite. The former is abundant throughout the sections in idiomorphic crystals, and is readily distinguished from the nepheline by its higher index of refraction. The nepheline is frequently quite fresh but sometimes shows alteration into a radiating zeolite which possesses the optical properties of natrolite. The alteration begins on the outer edge and the nepheline

crystals are, in many instances, bordered with a narrow edge of radiating zeolite needles. In association with this alteration is an alteration to colorless, brilliantly polarizing muscovite. The nepheline also weathers into an irresolvable, granular, whitish, dimly polarizing substance which may be kaolin. Some of the powdered rock, from which was excluded all phenocrysts except nepheline, was tested for the alkalies. Three-tenths of one gram of this powder, of which about one-half was nepheline, showed an alkali content as follows: soda, 8.32 per cent.; potash, 7.08 per cent. A sample of the powdered nepheline, very nearly pure, gave soda, 7.70 per cent.; potash, 3.74 per cent. The presence of a potash feldspar, as an orthoclase, in the groundmass would account for the high potash percentage in the first sample.

Augite.—Augite occurs in unmistakable, idiomorphic crystals of a violet color. There is a manifest pleochroism. $\mathfrak{c}$ = violet. $\mathfrak{a}$ = green. The crystals are frequently bounded by the prismatic and pinacoidal planes, giving octagonal cross-sections. Twinning parallel to the orthopinacoid is present, and zonal structure is not uncommon. Inclusions of apatite and magnetite are abundant. More rarely are found inclusions of olivine. The peripheries of the crystals show a narrow border of alteration to a uralitic, or to a reddish brown, hornblende.

Hornblende.—This mineral occurs both as phenocrysts and as a constituent of the groundmass. In the former case it is a rich red brown, with marked pleochroism and absorption. $\mathfrak{c}$ = reddish brown. $\mathfrak{a}$ = yellowish green. Cross sections show the hornblende angle. The hornblende-phenocrysts are not so numerous nor so large as the augite-crystals.

In the groundmass the slender lath-shaped, frayed crystals of a pleocroic reddish brown or a green hornblende are a conspicuous feature. These, which are abundant, together with biotite, augite and magnetite, are distributed through a colorless feldspathic matrix and constitute the dark-colored constituents of the groundmass. An alkali feldspar, a secondary muscovite, and minute specks of calcite constitute the colorless portion of the groundmass. The presence of calcium carbonate is attested

both by the brightly polarizing specks and by the effervescence of the powdered rock. Apatite is particularly abundant in fine crystals and may be included in any of the other constituents.

Olivine.—Olivine occurs characteristically in small crystals and rounded grains of the first generation. The high index of refraction, high double-refraction, parallel extinction, and dispersion of the still unaltered grains are all characteristic of olivine. It is, however, an inconspicuous and infrequent constituent of the rock, and is much altered to serpentine, hematite and magnetite.

In the order of their abundance the primary constituents should be named as follows: feldspar, nepheline, augite, hornblende and olivine. Both the feldspar and nepheline occur in greater abundance than any one of the ferromagnesian constituents and together constitute perhaps two-thirds of the rock mass. The structure is not so characteristically that of either a dyke or surface rock as to make it possible to determine the exact position occupied by the rock when cooling.

The character of the crystallization indicates the comparatively slow cooling of a "*hypabyssische*" rock. This crystallization may have taken place along the edge of a deep-seated magma, throughout an intrusive magma or in the central part of a surface flow.

A determination of the exact species of this rock from the study of a single bowlder must be more or less inaccurate and hence undesirable. Since a generic term only, can be affixed to the rock, the choice lies between the nepheline-syenite-porphyry and the theralite-porphyry groups. The highly alkaline character of the feldspars which constitute so large a proportion of the rockmass relates the rock perhaps more closely to the nepheline-syenite-porphyry group than to the theralite-porphyries. Like the nepheline-syenite-porphyries described by Brögger, it contains accessory olivine,[1] and comparatively

[1] W. C. BRÖGGER, Die Mineralien der Syenit-pegmatit-gänge der südnorwegischen Augit- und Nephelinsyenit. Groth's Zeitsch. für Krys. und Nien., Vol. XVI., pp. 32, 39.

abundant augite and hornblende.[1] A further justification of placing in the syenite group a rock showing so large an amount of the ferro-magnesian constituents is found in the new group of rocks recently described by Weed and Pirsson from the Highwood Mountains[2] and Yogo Peak,[3] Montana, in the lamprophyres of Gallatin, Jefferson and Madison counties, Montana, described by Merrill,[4] and in the banakites of the Yellowstone National Park and vicinity described by Iddings.[5]

Here we have a series of rocks with orthoclastic groundmasses combined with variable proportions of the ferro-magnesian silicates (augite, hornblende, biotite and olivine) with a wide silica range, all related to the syenite group.

Age.—That the drift material in the neighborhood of Columbus has its source from the north shore of Lake Huron in Canada and from northern Michigan was sufficiently indicated by petrographic study. Distinct types from the bowlders were matched both in the hand specimen and under the microscope to specimens taken from ledges in Canada and Michigan. While such matching was not valuable with the monotonous granites, gneisses and quartzites which constitute the great bulk of the bowlder material, a sufficient number of pronounced types were harmonized to establish both the age and the general source of the bowlder material.

Representatives of the Archæan, Algonkian, Cambrian and Lower Silurian formations are found among the bowlders. All the igneous material is undoubtedly pre-Cambrian or Cambrian. The presence of this member of the nepheline-syenite-porphyry group cannot be explained except on the supposition that it was, like the material among which it was found, brought

[1] W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes. I. Die Gesteine der Grorudit-Tinguait-Serie. Kristiania, 1894.

[2] Highwood Mountains of Montana, Bull. Geol. Soc. Amer., Vol. VI., p. 414.

[3] Igneous Rocks of Yogo Peak, Amer. Jour. Sci., Vol. L., No. 300, Dec. 1895, pp. 467–479.

[4] George P. Merrill, Notes on Some Eruptive Rocks from Gallatin, Jefferson and Madison counties, Montana. Proc. U. S. Nat. Museum., Vol. XVII., pp. 665.

[5] J. P. Iddings, Absarokite-Shoshonite-Banakite Series, The Journal of Geology, Vol. III., No. 8, Nov.–Dec. 1895, pp. 935–939.

to Ohio from a northern source, and is, like all the igneous drift material, of Cambrian or, more probably, pre-Cambrian age. A nepheline-syenite has been described by Dr. Adams[1] from southern Canada. A type related to the nepheline-basanite, Dr. Adams says, is known in Canada, in the vicinity of Montreal, where it forms dikes connected with the intrusive stock of Mt. Royal. There is no reason why a similar rock should not occur west of Montreal, and it may yet be described. It is impossible to say at present whether this nepheline-bearing rock is in any way related to these formations or is related as a dyke to some yet undescribed nepheline-syenite area on the north shore of Lake Huron. In any case it is a pre-Tertiary dike or surface, volcanic, resembling the modern type and thus affording another instance of the essential similarity of ancient and modern rock types.

F. BASCOM.

BRYN MAWR COLLEGE.

[1] F. D. ADAMS, on the occurrence of a large area of nepheline-syenite in the township of Dungannon, Ontario, Am. Jour. Sci., 198, pp. 10–18.

PETALOCRINUS MIRABILIS (*N. SP.*) AND A NEW AMERICAN FAUNA.

THE fossils described in the present paper were collected in Jones county, Iowa, by the junior author, Mrs. A. D. Davidson; the paper has been prepared by the senior author, Mr. Stuart Weller. The type specimens of the new species are deposited in Walker Museum at the University of Chicago.

The fauna of the Niagara period in America has much in common with that of the Wenlock limestone in England. There are at least thirty[1] species common to the two faunas, and the relationship is such as to make it seem most probable that during that period a shore line along which the fauna lived reached continuously across the Atlantic Ocean of today, joining the east American to the British regions. The fauna of the Gotland limestone of Sweden also has numerous species common to the Wenlock limestone and the Niagara. *Goniophyllum pyramidale* and the species of *Crotalocrinus* occur most abundantly in the Swedish beds though they are also present in the Wenlock limestone. The particular facies of the Silurian fauna containing *Goniophyllum* has not been generally recognized heretofore as American, and no crinoid has ever before been recorded which is at all closely related to *Crotalocrinus*.

Under these circumstances the discovery of a Silurian fauna in America containing specimens of *Goniophyllum* which cannot be separated specifically from those of the Swedish beds, associated with a crinoid whose nearest ally is *Crotalocrinus* is of extreme interest. Although it has seemed necessary to refer the crinoid not only to a distinct genus but even to a distinct family, it does not detract from the interest in the relationship of the faunas. It is well known that of all organisms which are preserved as fossils, none are more delicately adjusted to their

[1] Phillips Manual of Geol., Part II., p. 122 (1885).

environment than are the crinoids. Because of this it is not surprising that during a change or migration which did not even bring about a modification of the specific characters of the coral *Goniophyllum*, the generic and even family characters of the crinoid became modified. The peculiar family of *Crotalocrinidæ* has heretofore stood out alone among all the crinoids, and now a new family is discovered in America which is just as peculiar and whose bonds of relationship are strongest with the European *Crotalocrinus*.

Only a few of the most remarkable species of the fauna are described in the present paper. Corals are exceedingly abundant in the fauna, in fact it seems probable that these Iowa beds are the remnants of an ancient coral reef where many species of these animals flourished. It is hoped in the near future to make an exhaustive study of the whole fauna and its relationships.

PETALOCRINIDÆ (*n. fam.*).

No special description of the family will be attempted, all the characters, family, generic and specific, will be recorded under the description of the species.

PETALOCRINUS MIRABILIS (*n. gen. et sp.*).

Plate VI., Figs. 2–5.

The entire crinoid resembles a flower with five petals fully expanded, the five leaf-like arms representing the petals. The diameters of the calyces of the two perfect specimens in the collection with all the arms intact, are respectively $\frac{3}{16}$ and $\frac{1}{4}$ inch, the total expanse of the arms being $\frac{7}{8}$ and $1\frac{1}{8}$ inches. Some of the detached arms indicate individuals whose total expanse of arms was nearly two inches.

Calyx monocyclic, depressed. Basal plates 5, rhomboidal. In four of them the two outer edges are a little shorter than the inner; on the anal side the two outer edges are about equal to the inner. First radials resembling those in *Platycrinus*, a little wider than long, extending nearly horizontally from the basal plates. Second radials very short, free, as in *Platycrinus*, bearing the arms. They appear as thin plates intercalated

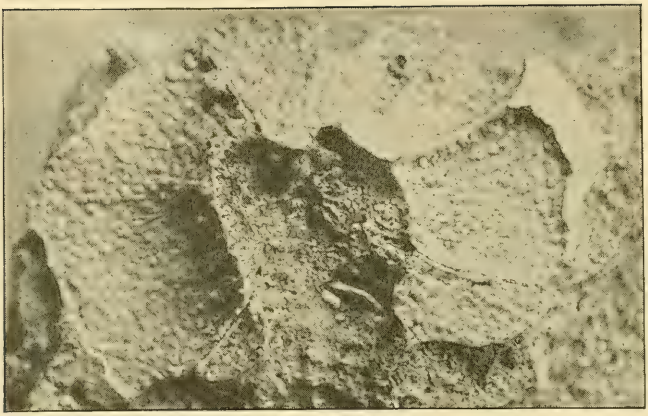

FIG. 1.

FIG. 2.

FIG. 3.

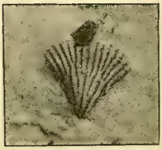

FIG. 4.

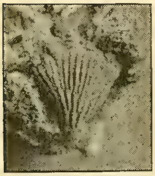

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

between the arm bases and the central portion of the outer edge of the first radials. No interradials observed on the dorsal aspect of the calyx. Ventral aspect unknown.

Arms triangular, leaf-like, rigid, gently curving dorsally. The plates composing them closely anchylosed, no sutures visible.[1] Dorsal side smooth, ventral side covered with longitudinal, rounded ambulacral grooves, separated by sharp ridges.

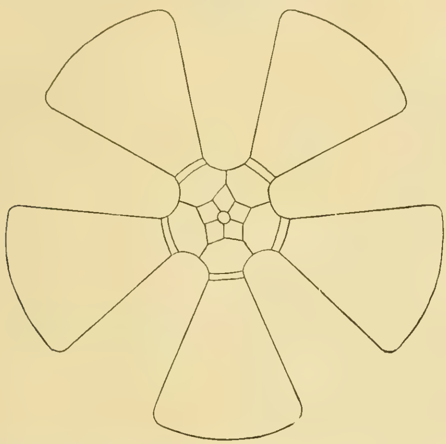

Fig. 1.—Outline view of the arrangement of the plates of the calyx and the relation of the arms to the calyx in *Petalocrinus mirabilis.*

Two ambulacral grooves start from the base of the arm, these bifurcate almost immediately, each of these four bifurcate and their branches bifurcate again, making sixteen ambulacral grooves at the distal edge of each arm.

Stem small, about one-sixth of the diameter of the calyx.

The structure of this crinoid does not conform to that of any described family, and it seems necessary to establish a new one for its reception. Were it not for the number of basals, the calyx alone would unhesitatingly be considered as belonging to *Platycrinus.* The most peculiar feature of the crinoid is its arms. In their broad leaf-like expanse they resemble somewhat closely those of the *Crotalocrinidæ*, but unlike the arms of the members of that

[1] The specimens are silicified, and in the process of silicification the sutures may have been obliterated. In another condition of preservation they might be observed.

family, they are perfectly rigid, standing out horizontally from the calyx and are entirely distinct from one another. They are also not nearly so greatly developed in *Petalocrinus* as in *Crotalocrinus*.

Fig. 2.—Idealized view of the ventral surface of an arm of *Petalocrinus mirabilis.*

The diameter of the stem is small, while in the *Crotalocrinidæ* it is almost as great as that of the entire calyx.

PETALOCRINUS (?) MAJOR (*n. sp.*).

Plate VI., Fig. 1.

A single imperfect specimen differs materially from the specimens of *P. mirabilis*. The calyx is entirely unknown, but from the arm structure it is placed provisionally in the genus *Petalocrinus*. The arms differ from *P. mirabilis* in being much larger and in being in lateral conjunction. The arrangement of the ambulacral grooves cannot be determined as the ventral surface is imbedded in the matrix. In the great expanse of the arms and their lateral conjunction this species approaches more nearly to the arm structure of *Crotalocrinus*, but differs from the species of that genus in their apparent rigidity.

GONIOPHYLLUM PYRAMIDALE [1] *Hisinger*.

Plate VI., Figs. 6–8.

829. *Turbinolia turbinata* var. *pyramidalis* Hisinger. Tableau des petrif. de Suede, Ed. 1, p. 22.

1831. *Turbinolia pyramidalis*, Hisinger. Tableau des petrif. de Suede, Ed. 2. p. 26.

1851. *Goniophyllum pyramidale* Milne Edwards & Haime, Polypiers fossiles, p. 404, Pl. 2, Figs. 4, 4*a*.

[1] For a complete bibliography of *G. pyramidale*, see Dr. Lindström's paper on the operculate corals.

1882. *Goniophyllum pyramidale* Lindström, Palæozoiska Formationernas Operkelbärande Koraller, p. 43, Plates 1, 5, 6, 7, 8, 9.
1890. *Goniophyllum pyramidale.* Am. Geologist, Vol. VI., p. 326.

The presence of *G. pyramidale* in the Silurian rocks of America has not been generally recognized, the short note in the American Geologist, which simply records the presence of the fossil in Iowa, being the only reference known to the writer. Dr. Lindström states in a communication to the writer that he has a single specimen of the species from Tennessee, which does not differ from the Swedish ones.

Dr. Gustaf Lindström has made an exhaustive study of the operculate corals, and he recognizes three forms of this species from the Swedish Silurian beds, viz., "*Forma primigena*," "*Mutatio prima*," and "*Mutatio secunda*." The Iowan specimens agree well with figures and descriptions and also with authentic Swedish specimens[1] of "*Mutatio secunda*" of Dr. Lindström. The species may be easily recognized by reason of its peculiar quadrangular form as shown in the figures. When perfectly preserved the calyx is covered by four triangular valves which form a pyramidal operculum. A single one of the Iowan specimens shows one of the operculum valves in position. The specimens vary among themselves in the amount of curvature and in the depth of calyx.

PENTAMERUS OBLONGUS *Sowerby*, *var.* CORRUGATUS, *n. var.*

Plate VII., Figs. 1–4.

This singular variety of *Pentamerus* is characterized by the criss-cross corrugation of the valves as is shown in the figures, and is apparently peculiar to this fauna. It is possible that it may become necessary to consider it as a distinct species, but as it does not differ from other variations of *P. oblongus* except in the criss-cross corrugation of the valves, and as this character is oftentimes faint or almost obsolete, it is thought best to accord to it but the taxonomic rank of a variety.

[1] The writer is indebted to Dr. Lindström for authentic specimens of *G. pyramidale* from Gotland.

FIG. 1.

FIG. 2.

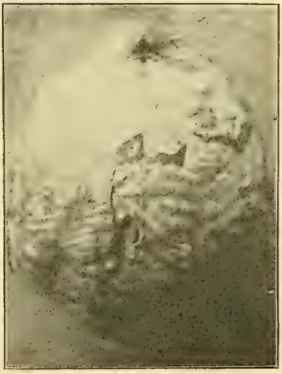

FIG. 3.

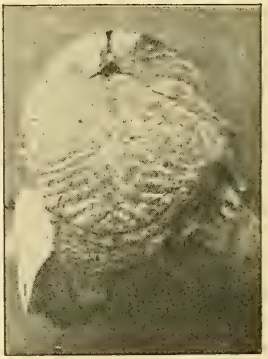

FIG. 4.

STRICKLANDINIA CASTELLANA *White.*

1876. *Stricklandinia castellana* (*N. S.*) White. Proc. Acad. Nat. Sci. Phil. p. 30.

1894. *Stricklandinia castellana* Hall & Clarke, Rep. N. Y. State Geol. for 1893, Vol. II., Pl. 49, Figs. 1–3, 5. (Handbook of Brachiopoda, Part II.)

As this species is found in association with the preceding it is thought advisable to make note of it here, and as the original description is somewhat inaccessible it is copied in full:

Shell moderately large, sublenticular, broadly subovate or subcircular in marginal outline; valves almost equally convex.

Dorsal valve usually showing a slightly elevated, indistinctly defined mesial fold, which is quite narrow upon the posterior portion of the valve, but widens towards the front, of adult shells; umbo broadly convex; beak not prominent.

Ventral valve usually having a slight flattening of the antero-median portion, corresponding with the indistinct fold of the other valve; umbo broadly convex; beak not prominent, projecting backward little if any beyond the beak of the other valve; area distinct, narrow, its length less than half the greatest width of the shell.

Surface of both valves marked by numerous, rather coarse, radiating, more or less recurving, angular or sharply rounded plications of unequal size and separated by spaces of unequal width.

Length and breadth of the largest example discovered, each forty-two millimeters; thickness, both valves together, twenty-one millimeters.

EXPLANATION OF PLATES.[1]

Plate VI.

Fig. 1. *Petalocrinus* (*?*) *major.*

Figs. 2–5. *Petalocrinus mirabilis.*

Figs. 2, 3. Two specimens showing all the arms in position.

Fig. 4. An impression in the chert of the ventral surface of a detached arm.

Fig. 5. Ventral surface of a detached arm.

Figs. 6–8. *Goniophyllum pyramidale.*

Plate VII.

Figs. 1–4. *Pentamerus oblongus var. corrugatus.*

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[1]All the figures are natural size.

REMARKS ON *PETALODUS ALLEGHANIENSIS* LEIDY.

In an article entitled "Description of a New Species of Petalodus," etc. (this Journal, Vol. III., No. 5), Dr. O. P. Hay describes an interesting specimen of a selachian tooth from the Carboniferous limestone of Illinois, for which he proposes the name *Petalodus securiger*. A number of characters are enumerated, in which the supposed new species is believed to differ from *P. alleghaniensis* and *P. destructor*, these two being regarded by the author as distinct. The article concludes with the suggestion that in case the identity of *P. alleghaniensis*, *destructor* and *securiger* ultimately be established, the name *P. ohioensis*, proposed by Professor J. M. Safford in 1853, should be reinstated on the ground of priority.

In the opinion of the present writer, all the forms described under the above names are identical, and as the validity of the well established title proposed by Leidy is brought into question, a few considerations may not be out of place in favor of its retention. These considerations would have been submitted much earlier, but for the fact that the writer has been awaiting an opportunity for comparing the Illinois specimen with the fine series of Petalodont teeth in the collection of the Museum of Comparative Zoölogy at Cambridge; he regrets, however, that a reported accident to the specimen has rendered it inaccessible to him.

As Dr. Hay does not state his reasons for preferring to regard *P. alleghaniensis* and *P. destructor* as distinct species, it may be as well to accept the opinion of Leidy, Newberry, St. John and others as authoritative, who hold that the two names are synonymous. In point of fact, less differences are to be noticed between specimens attributed to the above-named species than are exhibited by the teeth of the one species *P. acuminatus*

from limited localities in Yorkshire and Armagh. Attention has been called repeatedly to the great differences existing among detached teeth belonging to one and the same species, due to conditions of wear, age, geographical distribution, and other causes; and particularly to the wide range of variations displayed by teeth of the same individual, depending upon the position occupied in the mouth. In the case of *Petalodus*, we can infer what this second class of variations were, from analogy with the closely related genus *Janassa*. All of the minor differences in form and size which our author observes between *P. securiger* and *P. alleghaniensis* may be reasonably referred to this category.

The marked variation in the size of *P. alleghaniensis* correlating with geographical distribution has already been commented on by Newberry (Pal. Ohio, Vol. II., p. 53), the Ohio specimens being only about one-half as large as the western ones. Had our author compared his specimen with the figures and description of Leidy's type (Jour. Acad. Nat. Sci. Philad. [2], Vol. III., p. 162), instead of with the one figured in the Extinct Vertebrate Fauna, he would have found that the agreement is closer than he supposes; among other features, the number of basal enamel folds is precisely the same in both forms.

Finally, the rounding of the lateral angles (only one is preserved on Dr. Hay's specimen), can hardly be considered as of specific importance, since it, too, is a variable function; nor does the prominence of the enamel bands on the posterior surface appear to have any particular significance. The conclusion reached by the present writer is that at the most *P. securiger* is only a variety of *P. alleghaniensis*.

As to the availability of the terms *P. extinctus* and *P. ohioensis*, both are clearly untenable. Leidy's provisional designation of "*Sicarius extinctus*," proposed in 1856, was merely tentative, and unaccompanied by either figures or description of any kind. When, a few months later, the species was adequately described, this name was withdrawn, as was entirely proper, and that of *Petalodus alleghaniensis* substituted instead. In all probability

the specimen for which Safford proposed the name "*Getalodus Ohioensis*" was a true *P. alleghaniensis;* but this cannot be settled from the description, which is wholly insufficient, and the rough sketches of the tooth are not only unrecognizable, but, as Dr. Hay himself intimates, probably erroneous. Such being the case, it is in accordance with the ordinary rules of nomenclature that Professor Safford's term should lapse.

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Museum of Comparative Zoölogy,
Cambridge, Mass.

ON THE NATURE OF IGNEOUS INTRUSIONS.

In an article in the preceding number of this Journal, certain igneous intrusions in the vicinity of the Black Hills of Dakota, termed plutonic plugs, were described, and the similarity pointed out between the domes of sedimentary beds raised above them and the far greater dome from which the Black Hills have been sculptured. Other mountains of the Black Hills type in Wyoming and Colorado were also mentioned. In the present article I wish to direct attention to the fact that the dome-shaped uplifts referred to, form part of a genetically related series of disturbances caused by subterranean intrusions of igneous rock. Various stages in this series are shown by intruded sheets, laccolites plutonic plugs, and great dome-shaped uplifts of which the Black Hills furnish the type.

Intruded sheets.—As is well known, igneous rocks frequently occur in widely spread sheets, included between but litttle disturbed sedimentary strata. Although the enclosing sedimentary layers are frequently without conspicuous signs of having been disturbed, metamorphism of the sedimentary beds resting on the igneous rock at the surface of contact, furnishes proof that the latter was intruded in a molten condition between planes of bedding, after the sedimentary layers were consolidated. An example of an intruded sheet is furnished by the Palisade trap of New Jersey and New York. Including what is reasonably supposed to be a portion of this sheet, but which is separated from the main exposure by a covering of Cretaceous clays, its length measured along the curve formed by its outcrop is 90 miles. A straight line joining the most northern and most southern exposures is 70 miles in length. The sheet varies in thickness from about 300 feet at Jersey City, to at least 850 feet at

the High Torne, in Rockland county, New York.[1] The breadth of the surface now exposed by erosion, is from one to two miles. The central part of the sheet dips westward, in conformity with the enclosing strata, at an average angle of about 15°, but the dip increases toward the northern extension of the sheet, where irregularities occur. As shown by Darton, the dike that supplied the sheet, is exposed at a few localities on the western margin of the part now uncovered. The sheet does not, therefore, extend indefinitely beneath the sedimentary beds to the westward, as was at one time supposed. The Palisade sheet is remarkable for its extent and thickness, but except in these features, does not illustrate the facts to which I wish to direct attention, so well as many smaller examples of the same nature. In other portions of the Newark system, especially in the Connecticut valley, much thinner intrusive sheets occur, and many similar examples in other regions are familiar to most geologists. One of the best illustrations of the manner in which molten rock has been forced in between the strata of horizontally-bedded sedimentary rocks, which I have observed, may be seen in the precipitous walls of the canyon excavated by Purgatory River in Cretaceous terranes, in southeastern Colorado. The beds cut through in forming this canyon, include a sheet of basaltic rock four or five feet thick, which is exposed for three or four miles on each side of the gorge; so perfectly does it conform with the strata above and below, that even a careful observer seeing its outcropping edge for the first time from the bottom of the canyon, would not mistrust its intrusive origin.

In the case of the intrusive sheet exposed in Purgatory canyon, as already stated, the enclosing strata are horizontal. The same is true of similar sheets in many other regions. It is supposed with good reason that the intrusive sheets of the Newark system were forced in before the associated beds were tilted and faulted. The fact that intruded sheets are of frequent occurrence in regions where stratified rocks are yet horizontal is suggestive.

[1] N. H. Darton, "The relation of the traps of the Newark system in the New Jersey region," U. S. Geological Survey. Bulletin No. 67, p. 44.

During the intrusion of a sheet of molten rock between horizontal strata, it is evident that the beds above the plane of intrusion must be lifted. The force which lifts the superior layers must be the dynamical energy of the intruded molten rock, aided perhaps by the steam generated when the highly heated magma came in contact with water. If intruded sheets were confined to the side of folds or to regions deformed in other ways, it might be suggested that the force which deformed the rocks tended to separate the strata, thus lessening the work that the intruded rock had to perform in order to make room for itself, but as intrusive sheets seem to be most common if not confined to regions where the receiving terrace is horizontal or was yet undisturbed at the time the intrusion took place, no such assistance can be claimed. That the receiving terrane should be practically horizontal at the time extensive intrusive sheets are formed, seems an essential condition, since folded and tilted strata are apt to be broken and faulted, and would thus furnish passages for the escape of the molten rock forced in among them under great pressure, and dikes and not sheets would result. Also, horizontally stratified beds would offer less resistance to the advance of an intruded sheet among them, than similar beds when folded, since the force necessary to split open the even grain of the horizontal beds, would be less than the force required to separate the contorted grain of folded beds.

Another significant fact, as shown by observation, is that intruded sheets of wide extent at least, are composed of basaltic rocks, that is of the most easily fusible of igneous rocks. Rocks of which basalt may be taken as the type form highly fluid magmas when heated to 2000° or 2500° F., a temperature at which more siliceous rocks like rhyolite, are still solid or at most only viscous. Intruded sheets, therefore, seem to have been formed by the injection of highly fluid magmas under great pressure. Just as easily fusible basaltic lavas, when ejected from volcanoes, tend to spread widely over the surface, so highly fluid magmas, when forced between stratified beds, spread out in thin intruded sheets. As highly viscous magmas, when extruded at

the surface, flow sluggishly and frequently come to rest in thick masses even on steep slopes, it is to be inferred that if such magmas were intruded in a manner similar to that by which sheets of basalt are spread between sedimentary strata, they would expand much less widely. This difference in freedom of flow between magmas that are easily fusible and those that are refractory, appears to be one of the conditions which determines whether a body of highly heated rock intruded among horizontally stratified beds, shall spread widely and form a sheet, or be restricted in its lateral expansion and cause a more local uplift of the strata above it.

Another condition which would influence the behavior of an intruded magma, is the depth in the earth's crust at which the intrusion occurs. Since the rocks above the intruded magma have to be lifted, the higher in the series the intrusion occurs, the less the weight of the rocks above, and the greater the amount of energy available for lateral expansion. If variations in the specific gravity of strata are not considered, the conditions favoring the formation of intruded sheets, increase as the magma approaches the surface, until the tendency of the lifted strata to fracture determines a limit. We should expect, therefore, that intruded sheets would be most numerous in the upper portion of the earth's crust. The correctness of this inference can be tested to some extent by observation. The date at which many intrusive sheets were formed, however, and the amount of subsequent erosion that has taken place, are frequently difficult to determine and space will not permit of the introduction of evidence in this connection. The fact that the edges of intruded sheets are frequently exposed in canyon walls in regions of topographic youth, certainly favors the conclusion that widely extended intrusive sheets are comparatively superficial phenomena.

In order to bring the ideas which I wish to present to a focus, let us consider other phases of igneous intrusion.

Laccolites.—The difference between a widely extended intrusive sheet and a local cistern-like injection of molten rock, or a laccolite, so far as the shape of the intruded mass is concerned,

is mainly in the degree of lateral expansion. In what may be termed their genetic features, these two classes of intrusions are essentially similar. In each case molten rock rises from below into stratified beds, probably through fractures, and on reaching the upper limit of the fractures lateral expansion takes place and the strata above are lifted. The main conditions, as we have seen, which control the extent of the lateral expansion, besides the propelling force and the occurrence of fractures or other openings through which the molten rocks rise, are the fluidity of the magmas, and the depth in the earth's crust at which they reach the upper limit of the passage-way through which they came, and tend to spread horizontally. Under the same conditions respecting temperature and pressure, we should expect refractory magmas to form laccolites, while more easily fusible rock would be more apt to spread out in sheets.[1] We should expect laccolite, therefore, to be composed of less easily fusible rocks than are found in widely extended sheets. Again we may test inference by observation. It is usually conceded that the amount of silica in a rock determines its degree of fusibility. Acid rocks, as a rule, are more refractory than basic rocks. Dana has qualified this conclusion, however, by showing that it is the fusibility of the chief constituent minerals in a lava which determines its mobility. He says: "Trachyte and rhyolite are the least fusible of igneous rocks, because the constituent feldspar, orthoclase, is the least fusible of the feldspars; and basalt or dolerite is one of the most fusible, because the feldspar present, labradorite, is of easy fusibility, and it is combined in the rock with still more fusible augite and pyroxene."

In a recently published report on the laccolitic mountains of

[1] Intruded sheets do occur in connection with the laccolites, and are composed of off-shoots of the same material. Sometimes these sheets, as stated by Cross, extend four or five miles from the main intrusion. As shown in sections of Henry Mountains, given by Gilbert, the associated dikes and sheets are in the disturbed strata above and immediately about the main body of the laccolites. The opening of the deformed strata by the disturbance caused by the principal intrusion appears to have had much to do with the origin of the secondary phenomena. It does not seem to me that the comparatively small sheets originating in this manner furnish an exception to the generalization suggested above.

Utah, Colorado and Arizona, Cross[1] states that the rocks composing these intrusive bodies all belong to a well marked structural type and present but slight variations in mineralogical composition. Plagioclase is the predominant mineral of all the rocks — excepting the quartz-porphyry — and the uniform appearance of its stout white crystals gives character to the whole series. Which of the feldspars composing the group known as *plagioclase*, are most common in these rocks is not clearly stated, but in a table of nineteen analyses, the percentage of silica ranges from 56.62 to 73.50, and of alumina 14.87 to 18.00. The rocks are therefore highly siliceous, and, I think I am justified in concluding, highly refractory, in comparison with the basaltic rocks of which widely extended intrusive sheets are composed.

It appears, therefore, that the nature of an intruded magma, whether highly fluid or viscous, has much to do with the form in which it solidifies. The degree of fusion depends, of course, on the amount of heat. Even the most refractory rocks, when sufficiently heated, will become highly fluid, under normal surface pressure. Since the interior heat of the earth increases with depth, refractory rocks would remain unmelted, or perhaps be partially fused and viscous, at a depth where the most easily fused igneous rocks would be highly fluid. This would lead us to expect also that laccolites would be formed deep in the earth's crust. This inference can be checked by observation. Evidently, if laccolites are now exposed at the earth's surface, the amount of erosion that has taken place in the disturbed beds above them will show how deeply they were originally buried. In the case of the Henry Mountains, Gilbert shows that the domes of stratified beds removed were possibly 7700 feet thick.

The relative specific gravity of intruded magmas may also be expected to influence their behavior, and especially the height to which they would rise under a given pressure, but this seems to be a minor feature of the problem. The force with which magmas are injected is, of course, the main cause which deter-

[1] U. S. Geological Survey. Fourteenth Annual Report, pp. 224, 228.

mines this behavior, but the principle which interests us most at present, is that different magmas under the operation of similar pressure tending to intrude them, would behave differently. The conditions that modify and limit the formation of laccolites have been fully discussed by Gilbert,[1] and need not be reviewed at this time.

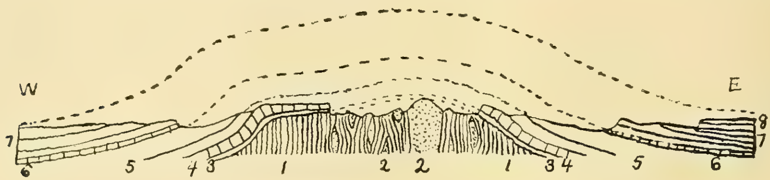
Plutonic plugs.—In a previous article in this JOURNAL, already referred to, I have directed attention to the plug-like intrusions that occur in the Black Hills region. These intruded masses have been classed as laccolites by Crosby, and possibly the variation they present from that type is not sufficient to necessitate a separate consideration. They occur in a region where the stratified rock into which they were forced are essentially horizontal, and where dikes and other evidences of fracture are absent, and where deep erosion has occurred. They are formed of refractory acid rock. The principal mineral constituent, according to Casswell, is always sanadine.

The Black Hills of Dakota.—As pointed out in the essay referred to above, and as previously stated by Newton in his report on the Black Hills, the domes of sedimentary strata upheaved by the intrusion of plugs of igneous rock in the case of the Sun Dance hills, Inyan Kara, etc., are structurally identical with the vast Black Hills dome. In each case previously horizontal strata were raised by a force acting from below vertically upward, so as to form a dome from the summit of which the layers dip away in all directions. The dome known as Little Sun Dance hill is unbroken by fractures and the summit of the plug of igneous rock inferred to exist beneath it, is not exposed. The absence of dikes in connection with the associated uplifts indicates that they, also, were not fractured as they rose, so as to allow the fluid rock beneath to escape. The absence of dikes indicates that the intrusion of the plugs took place at great depths, and that the upraised strata were under heavy pressure. The strata, after being upraised, were certainly of greater superficial extent than previously, when horizontal, and a stretching

[1] Report on the geology of the Henry Mountains.

and thinning of the beds over the summit of the dome is to be inferred, but thus far has not been observed.

The Little Sun Dance dome is about a mile in diameter. The Inyan Kara dome measures about two miles in diameter. The similar dome from which Warren Peak has been sculptured, was two or three by eight miles in diameter. The Black Hills dome, as shown by Newton and Gilbert, is less regular in ground



IDEAL CROSS-SECTION OF THE BLACK HILLS.

Vertical scale 5–6 times horizontal. Dotted lines indicate portion of uplift removed by erosion.

1. Archæan slates and schists.
2. Granite.
3. Potsdam unconformably on 1 and 2.
4. Carboniferous.
5. Red beds.
6. Jura.
7. Cretaceous.
8. White River Tertiary unconformably on 7.

plan than those just mentioned, and measures 70 by 160 miles in diameter.

The plugs of igneous rock which lead to the elevation of the Inyan Kara and several associated domes, have been exposed by erosion, and rise boldly in the center of the encircling rings formed by the truncation of the domes that formerly arched over and concealed them. In the center of the concentric outcrops of stratified rocks forming the outskirts of the Black Hills, there is a mass of schists into which a core of granitic rock has been intruded. The succession of stratified rocks forming the dome, and their relation to the schists and granites within, is shown in the following section copied from Newton and Gilbert. It is to be remembered that any cross section through the Black Hills uplift would show the same structure, although the details would be varied.

The schists shown in the central part of the section, belong to the series of stratified rock resting on them, so far as the origin

and general structure of the uplift are concerned, and shared in the disturbance that elevated them. Whether the core of intruded granite answers to the plutonic plugs forming the cores of the smaller domes or has itself been elevated by an intrusion of molten rocks beneath, will be considered in advance.

Under this view of the origin of the Black Hills dome, the supposed intrusion of molten rock took place deep below the surface, and on account of the vast weight to be lifted, and probably also by reason of its viscosity, did not expand into a broad sheet, but as in the case of true laccolites, and plutonic plugs, produced a local elevation. The deeper the horizon at which the intruded rock expanded, the broader would be the dome formed above it. The outline of the dome raised on the surface would depend on the form of the cistern of molten rock beneath, and perhaps on the dip of stratified beds before the intrusion occurred. If the subterranean cistern was supplied through an extended fissure, an elongated dome or a ridge-like elevation at the surface would result. The domes produced by the injection of plutonic plugs, as already stated, are nearly circular, but the major axis of the Black Hills dome is double the length of the minor axis. The form that the elongated Black Hills dome would present, had there been no erosion, is shown on a contour map by Newton and Gilbert.[1]

The influence of dip on the form of an uplift produced in the manner above considered, is probably not important, as it is doubtful if such deformation occurs in rocks that are not essentially horizontal.

Mountains of the same type as the Black Hills but in which the difference between the horizontal axes is greater, occur in the same general region.

The mountains of Wyoming and Colorado.—The Big Horn Mountains, Wyoming, are of the same type as the Black Hills uplift, but the dome from which they were sculptured was more elongated than is the case of the Black Hills dome. The trend of the range is approximately northwest and southeast, but is

[1] Report on the Geology of the Black Hills, plate opposite page 208.

concave on the west, the longer diameter of the now truncated dome is 160 miles and its shorter diameter about 50 miles. At the south this uplift merges with another of similar character which trends more nearly east and west and has been deeply eroded. Its central mass of weathered granite forms the Wind River Mountains. Mountains having the same structure, extend southward into Colorado, and form several ranges designated by Powell as the Park Mountains. Each of these dome-like uplifts of Wyoming and Colorado has been deeply eroded, and broad central cores of granite exposed and sculptured into bold topographic forms. Sections through the mountains of Colorado from east to west, published in the "Atlas of Colorado," by Hayden, and the atlas accompanying the reports of the Fortieth Parallel Survey, show great central masses of what is termed metamorphic granite. On the flanks of these central masses the sedimentary strata underlying the adjacent plains, are sharply upturned. In many instances the central granitic cores are from 20 to 30 and even 50 to 60 or more miles across.

These dome-like arches are clearly not anticlinical folds; although, that such was their origin has frequently been stated. Nothing in the Appalachian or other similar ranges, formed by the crumpling of stratified beds by lateral compression, corresponds with them. Experiments with plastic material in illustration of the formation of anticlines and synclines, do not suggest that such broad, simple arches surrounded by horizontal strata can be produced in the same manner. These great upward bulges are similar to the Black Hills dome, the only conspicuous difference being that they are much elongated. If we arrange in a series, cross sections of the Black Hills, Big Horn, and Wind River Mountains and of several of the ranges included in the Park Mountains, it will be seen that a single type of uplift is shown in all cases. The same fact will appear also if restorations of the various domes as they would appear had there been no erosion, are placed side by side. That several of the more prominent ranges of Wyoming and eastern Colorado are of one type, was recognized by Hayden, who considers them, however,

as have others, of the nature of anticlinals produced by lateral compression. He says:[1]

> In general terms, while the details are extremely complicated, we may express the structure of a belt of country known as the Sawatch range (in east-central Colorado), eighty miles in length from north to south, and at least forty from east to west as a single wedge of granite, thrust upward, and the sedimentary rocks inclined from either side. The illustration of which the Sawatch range is the central mass is probably on a grander scale than any other in the West, but there are abundant examples of smaller size. The Black Hills of Dakota, the Laramie range, Big Horn, Wind River and many others are of the same type.

The cores exposed in the Black Hills, Big Horn and other mountains referred to above, are of granite. Whether these granitic centers answer to the plutonic plugs in the smaller domes to the northward of the Black Hills, or belong structurally to the sedimentary beds upturned on their flanks, and have themselves been elevated by intrusions beneath, is not clear. I am inclined to the hypothesis, however, that the granite was the floor on which the sedimentary beds were deposited and that it has itself been elevated with them.

The magnitude of the elongated domes from which the present mountains of Colorado and Wyoming have been sculptured, might perhaps be urged as an objection to the view of their origin here expressed. As it will tend to make us more cautious if the size of the problem we have attacked is fully realized, let us endeavor to form a mental conception of the region referred to as it would appear under this hypothesis, if unaffected by erosion.

On the summit of Mt. Lincoln, Colorado, 14,297 feet above the sea, there are, according to Hayden, clastic beds belonging to the same series as the strata upturned on the flanks of the mountains of which Mt. Lincoln is one of the dominant peaks. No one who is familiar with the geology of Colorado will dispute, I fancy, that this and other similar evidence, may be taken as proof that the granite now forming the central

[1] U. S. Geological and Geographical Survey of the Territories, annual report for the year 1873, p. 49.

peaks of the several ranges termed the Park Mountains, was once covered by an extension of the formations now found beneath the intervening valley, and upturned on the flanks of the uplifts.

As the central cores of granite now rise between seven and eight thousand feet above the adjacent border of the Great Plains, the refilling of the gorges and valleys excavated in their sides, so as to restore what would have been the surface contour of the granite had there been no erosion, would produce an elongated dome rising at least seven or eight thousand feet above the adjacent plain on the east. If we add to the surface of this dome the thickness of sedimentary beds now upturned in its eroded flanks, its height will be increased by seven or eight thousand feet; this being the approximate average thickness of the upturned border of the strata that extend horizontally beneath the Great Plains.

The most severe test of the hypothesis before us, in respect to the magnitude of the results reached, is furnished by what is known as the Front Range of the Rockies in Colorado and Wyoming. This range is probably not the result of the wearing away of a single dome, but as the central granite core now exposed is continuous from Central Wyoming to southeastern Colorado, a distance measured along the curve of the outcrop, of about 400 miles, we will consider it for the present, as an individual uplift. The average breadth of the granite is between twenty and twenty-five miles. The great elongated dome from which the Front Range of the Rockies has been sculptured, would therefore if uneroded, have a length in excess of 400 miles, a breadth of probably 40 or 50 miles and a height above the level of Denver of 15,000 to 16,000 feet.

This result reached by pressing our hypothesis to its logical conclusion—and assuming in order to make the test as severe as possible, that the Front Range is a single uplift—is startling, it is true, but no more so than the measures of the amount of erosion that have been obtained in an adjacent region. In the Uinta Mountains, Powell finds that the mean thickness of rock

which has been eroded away from a large area, is 18,500 feet, and in the axial region of the mountains, is 25,000 feet.

From the broad oval summit of the great dome we have restored in fancy by prolonging the remnants of the base of the arch over the central granitic peaks, we can see lesser domes which form a series and lead step by step down to the Little Sun Dance dome, a mile in diameter, the inner layers of which remain to this day unbroken.

As the type of mountain briefly described above is distinct from other types usually recognized, it will be convenient to designate it by an appropriate name. To meet this want, I venture to suggest that uplifts which owe their origin to the intrusion of a molten magma into the rocks beneath them, be termed *subtuberant mountains.* They may be fancied to originate from the growth of a tuber within the earth's crust.

General conclusions.—From the facts to which attention has been directed, it seems to me that a sequence is traceable between: (1) Intruded sheets of the Palisade type, formed by highly fluid magmas spreading widely between horizontally stratified beds, and lifting a broad cover without producing conspicuous topographic changes or marked disturbances in the upraised beds. (2) More local intrusions of less fluid magmas forced into horizontally stratified beds, which raised the strata above into domes, as is the case of the Henry Mountains, the Sun Dance hills, etc., and (3) deeply seated intrusions probably of highly viscous magmas, which raised vast domes of sedimentary rock and the floor of metamorphic rock on which they repose, as in the case of the Black Hills, Big Horn, and Park Mountains.

To the question, whence came the force that was enabled to intrude sheets of molten material scores and even hundreds of square miles in area, between sedimentary layers, and lift beds of rock of the same extent and, in at least some instances, many hundreds of feet thick; or elevate domes from 50 to 200 miles or more in diameter, to a height of several thousand feet, only general answers can be given.

On the theory that the interior of the earth is in a highly

heated and plastic condition and enclosed in a more rigid shell which contracts as it cools, a force is brought to bear on the plastic interior which tends to squeeze it out whenever an opportunity is afforded. The idea is not that the crust of the earth is a cold and solid shell enclosing a molten interior, the surface of contact between the two being sharply defined; but rather that the highly heated and plastic interior passes by insensible gradations into a cooler and more solid exterior, the outer surface of which is cold and rigid. The crust is still losing heat and consequently contracting and thus brings a pressure to bear not only on the interior mass but on the material forming the crust itself. On account of irregularities and unequal cooling, regions well within what may be termed the crust, may still be in a molten condition. Such bodies of plastic material may differ from the rocks enclosing them, as well as vary in composition among themselves, by reason of having reached different stages in the process of change from a molten to a solid condition. Here again we are departing from observed conditions, and have only the imagination to guide us, as there are no tests available by which the truth of our conceptions can be verified.

Under the conditions assumed, when a fissure is formed in the earth's crust, the deeply seated fluid or plastic material within, is forced out and becomes more and more fluid as it rises and pressure is relieved, unless this tendency is more than counteracted by the decrease of fluidity due to loss of heat. When such fissures open a way to the surface volcanic phenomena ensue. If the fissures do not reach the surface but terminate in horizontally stratified rocks, the molten material which rises in them may spread more or less horizontally between the strata and form sheets, or exert its force locally and cause a dome to rise, according to its viscosity, the depth below the surface, etc.

Nothing less than the force produced by the contraction of a cooling globe seems adequate to account for the results to which attention has been directed. The slowness with which the earth has lost heat and the consequent slowness with which contraction has acted on the still plastic interior or still plastic reservoirs

in the crust itself, is in harmony with the gradual bending of strata thousands of feet in thickness, as seen in the Black Hills, Big Horn Mountains, etc., without producing fractures through which the igneous material could escape.

Certain broad physical features of the earth seem in harmony, also, with the views here advanced. It has long been recognized that volcanoes are arranged about the borders of continents, and on the ocean's floor. So far as the association of oceanic waters is concerned with the origin of volcanoes, this arrangement is now considered accidental. But as shown by Dana, volcanoes mark lines of weakness in the earth's crust. These lines of weakness may reasonably be supposed to be the direction taken by the fractures during an early stage in the cooling of the globe and to have continued to be the lines of weakness along which movements have taken place from time to time, down to our own day. In the central portions of continental areas, active and recently extinct volcanoes are much less numerous than near continental margins. In the case of those that do occur far inland, as in the Great Basin region, there is plain evidence that the rocks of the earth's crust have been broken, and the region is as much a line of weakness as if it chanced to be adjacent to the sea.

While active and recently extinct volcanoes are notably absent from the central portions of continental areas, it is equally true so far as can be judged from available data, that subtuberant mountains are confined to such central regions. This follows also from the conclusions that broad areas of horizontal and unbroken stratified rocks are favorable for the formation of extensive intrusions.

The central portions of continental areas although not lines of weakness in the sense used by Dana, are regions of denudation and, as has been recognized by several American geologists, may be considered as relatively light areas, in comparison with continental borders, where maximum sedimentation takes place. It is in regions where the earth's crust is relatively light, when fractures are absent, and where the strata are essentially horizon-

tal, that pressure brought to bear on the plastic interior—either by reason of the cooling and contraction of the earth's crust, or by the shifting of material on the surface, in the constantly active processes of denudation, transportation and sedimentation—would most reasonably be expected to cause the rocks to bulge upward into domes.

If the above considerations are well founded we should expect to find subtuberant uplifts in the central portions of continental areas, but not about their borders. Here, again, it would be well to check inference by observation, but so far as I am aware, mountains of the type referred to, have not been recognized outside of the United States. Although unable to verify our conclusion, at present, we can leave it as a prediction, the truth or fallacy of which will appear as exploration is continued.

Analogies between subterranean and surface igneous phenomena.—Certain analogies between the phenomena associated with subterranean intrusions and with surface extrusions or volcanoes, are of interest.

Quiet eruptions of highly liquid basaltic lava, like those characteristic of the Hawaiian volcanoes, are represented below the surface by widely extended intrusive sheets of similar material. The thick and sluggish volcanic flows of rhyolite of the character to be seen on the side of the Mono craters, California, are suggested by the cistern-like intrusions of refractory porphyrite, forming laccolites, and still more strongly by plutonic plugs in which no lateral expansion has been recognized. Fissure eruptions, like those that furnished the Columbia lava of Idaho, Washington and Oregon, or the Deccan traps of India, so far as the energy manifest, and the extent of topographic changes produced, are concerned, find more than a counterpart in subtuberant mountains.

Extremely violent volcanic explosions occur when large bodies of water come in contact with molten lava. A molten magma rising from a deeply seated source in the earth's crust, as a rule, invades strata that are more and more highly water-charged, the nearer it approaches the surface. A secondary

result of such an intrusion is the generation of steam. In the case of the intrusion of a plutonic plug for example, steam may be generated and assist in raising the dome that is formed in the stratified beds above. When a plutonic plug on approaching the surface comes in contact with subterranean water, sufficient steam may be generated to blow away the dome above. Surface explosions sometimes remove large portions of volcanic mountains, as in the case of Krakatoa, Somma, Santorin, Barren Island, Coseguina, Crater Lake, etc.; plutonic explosions may reasonably be supposed to remove domes of stratified rock (consisting either wholly of sedimentary beds, or made up in part of lava sheets), and form crater-like depressions termed crater-rings, calderas, etc., as in the case of Coon Butte, Arizona; Lonas Lake, India; and still greater cavities, like those occupied by Lakes Bolsena and Bracciano, Italy, the former of which is circular and six and one-half miles in diameter, and the latter less regular, with a north and south diameter of ten and one-quarter miles, and a breadth of nine miles.

The breaking of the steam bubbles that rise through the boiling lava in the crater of Vesuvius cause the summit of the mountain to tremble with miniature earthquake shocks. When the throat of the volcano becomes clogged, steam generated within breaks through the obstruction or rends the mountain with such violence that the region for miles around is severely shaken. Subterranean intrusions of molten rock on coming in contact with water, may reasonably be supposed to cause similar steam explosions of which the only surface manifestations would be earthquake shocks.

Since my essay on the plutonic plugs of the Black Hills region was published, my attention has been directed to the fact that the rocks, of which some of the plugs are composed, have been recently studied in the light of more modern petrographical methods than were employed by Caswell. L. V. Pirsson, states, in the Am. Jour. Sci., Vol. XLVII., 1894, pp. 341–346, that the rock forming the cores of Mato Teepee and the Little

Missouri Buttes, is phonolite, instead of sanadine-trachyte, the conspicuous feldspar being "soda-orthoclase or anorthoclase." A chemical analysis of the rock gave SiO_2 61.08, and Al_2O_3 18.71. "A vertical dike about fifty feet wide, cutting through the schist and Palæozoic series in the mountains south of Deadwood," observed by C. E. Beecher, is also mentioned.

Observations by W. M. Dawson, W. H. Weed and L. V. Pirsson, seem to show that domes with cores of plutonic rock and surrounded by horizontally stratified beds, similar to the domes with plutonic plugs in the neighborhood of the Black Hills, form the Sweet Grass Hills and Zogo Peak, Montana.[1]

Errata.—The titles of Figs. A and B, Plate II., Vol. IV. of this JOURNAL, should be transposed. The title for Fig. A should read, "Little Missouri Buttes from the East."

ISRAEL C. RUSSELL.

[1] "Report upon Country in the Vicinity of Bow and Belly Rivers, Northwest Territory, in Geol. and Nat. Hist. Sur. and Mus. of Canada, Report of Progress, 1882–3–4, c. pp. 16, 45.

W. H. WEED and L. V. PIRSSON, "On the Igneous Rocks of the Sweet Grass Hills, Montana," in Am. Jour. Sci., Vol. L., 1895, pp. 309–313.

L. V. PIRSSON, "On Some Phonolitic Rocks from Montana," in Am. Jour. Sci., Vol. L., 1895, pp. 394–399.

W. H. WEED and L. V. PIRSSON, "Igneous Rocks of Zogo Peak, Montana," in Am. Jour. Sci., Vol. L., 1895, pp. 467–479.

STUDIES FOR STUDENTS.

DEFORMATION OF ROCKS.[1]

I. GENERAL.

ROCK units under thrust act very differently, depending upon their thickness, strength, and other characters, upon the character and thickness of the rock units above and below, and upon the closeness of the folding.

It is believed that the outer part of the earth may be divided into three zones: (1) An upper zone of fracture; (2) a middle zone of combined fracture and plasticity; (3) a lower zone of plasticity.

(1) *Rocks under less weight than their ultimate strength when rapidly deformed are in the zone of fracture.* That is, when rocks under such conditions are deformed they break, and crevices small or great separate the broken parts. The fractured rocks may be jointed, faulted, or brecciated in a simple or complex manner. The fractures may be far apart and of great size and extent, or near together and of small size and extent. Innumerable parallel fractures may occur in the same direction when, as shown in a subsequent paper, the rocks develop a parting or fissility. In extreme cases of fracture the rocks become autoclastic or are broken into innumerable fragments by the forces of deformation. These

[1] Published by permission of the Director of the United States Geological Survey. In the preparation of this series of papers I have been greatly assisted by PROFESSOR L. M. HOSKINS. In the Sixteenth Annual Report of the United States Geological Survey, where my entire paper will appear, PROFESSOR HOSKINS'S work, from which extracts are below made, will also be published. To WILLIS'S paper upon the Appalachians I am also greatly indebted. ("The Mechanics of Appalachian Structure," by BAILEY WILLIS, Thirteenth Ann. Rept. U. S. Geol. Surv., pp. 211–281.) I should also mention HEIM'S great work, "Mechanismus der Gebirgsbildungen," from which I have absorbed many ideas.

fragments may be rounded, and such rocks resemble ordinary clastic rocks. In this case the rock becomes a pseudo-conglomerate, and there are all gradations between such a rock and one in which the cracks and crevices become subordinate, the deformation being chiefly that of flowage. For a soft shale, but a small thickness of superincumbent strata, possibly 500 meters or less, may prevent any considerable fractures and crevices from forming. For the strongest massive rocks, a great thickness of superincumbent strata, possibly nearly 10,000 meters, may be necessary to prevent cracks and crevices from forming.

Heim states that it is impossible for crevices and cracks to exist at so great a depth as 5000 meters.[1] From geological observations I have for some time been convinced that a greater depth than this is required to close crevices under some conditions. The depth at which a cavity of any definite size begins to close will depend upon its form, upon the strength of the rock, upon whether the rock is saturated with water, upon the increased plasticity of the rock due to the rise of temperature with increased depth, upon the amount of lateral thrust, and upon the length of time during which the rock is subjected to stress.

So large an opening as the St. Gothard tunnel, 6.4 meters high and 8 meters wide, exists with no observed tendency to close under an irregular dome of rock which for some distance is more than a mile thick and has a maximum thickness of 1830 meters. The thickness of the superincumbent rock diminishes from the maximum to nothing at the ends of the tunnel. However, it would appear from this case to be highly probable that in order to close cavities the maximum number must be multiplied by a factor of considerable magnitude.

It would seem that mathematicians and physicists, after experiments upon the plasticity of rocks of different kinds, ought to give an approximate solution of the problem as to the depth at which cavities in any kind of rock would begin to close. We need long continued experiments upon the plasticity of different rocks at various temperatures and pressures, and while the rocks

[1] Mechanismus der Gebirgsbildungen, by ALBERT HEIM, Band II., 1878, p. 110.

are saturated with superheated water. We also need a satisfactory theory of the flow of viscous liquids or plastic solids.

In the absence of these data a first approximate solution of the problem has been made by Professor L. M. Hoskins, of Stanford University, based upon the elastic limit and the ultimate strength of rocks. The most carefully conducted experiments agree with theory and seem to show that rock masses of the same form have the same crushing strength per unit of area whether in large or small masses. In experiments on cubes running from 1 to 12 inches in diameter,[1] in each set there are irregular variations per unit area on each side of the average, but these are probably explained by the unavoidable variations in the strength of the different pieces tested and the impossibility of obtaining exactly similar conditions.

Professor Hoskins, after a comprehensive discussion, reaches the following general conclusions upon the closing of cavities in rocks:

(I.) In any region if the three principal stresses of a rock mass are equal, a spherical cavity cannot exist permanently if the normal stress in the rock exceeds the pressure within the cavity by as much as two-thirds the elastic limit or the ultimate strength.

(II.) If two of the three principal stresses are equal, a cylindrical cavity of considerable length whose axis is parallel to the third direction cannot exist permanently if either of the equal principal stresses exceeds the interior pressure by as much as half the elastic limit or the ultimate strength, or if the third principal stress exceeds the interior pressure by as much as half the elastic limit or ultimate strength.

Although the discussion has been confined to these special cases, it seems safe to state the following general proposition as at least probably tiue:

(III.) No cavity can exist permanently in a rock throughout a considerable portion of which the normal stress in any direction exceeds the pressure within the cavity by as much as the elastic limit or ultimate strength of the rock.

Professor Hoskins further says that:

The intensity of stress upon a horizontal plane at any depth is equal to the weight of a column of rock of unit cross-section extending to the surface.

[1] Tests of metals and other materials for industrial purposes, made with the United States testing machine at Watertown Arsenal, Mass., by S. V. Benét, Chief of Ordnance. Rept. of Chief of Ordnance for year ending June 30, 1884, pp. 126, 166, 167 188–199, 212, Washington, 1886.

In applying these results to ascertain the depth at which cavities would close, the following additional assumptions are made: Some of the cavities are supposed to have a form best adapted to resist closing. In most cases, as shown by Professor Hoskins, this is probably spherical. The cavities are supposed to be very small as compared with their depth below the surface, so that the pressure due to gravity is practically the same for all parts of a cavity. The rocks are assumed as being among the strongest—that is, having a crushing strength of 1700 kilograms per square centimeter. This amount somewhat exceeds the average crushing strength of the ordinary crystalline rocks, such as granite and schist, but is surpassed by about one-fifth in some of the very strongest hornblende-granites and basic rocks. It is probable that the stronger, and perhaps the strongest, rocks should be chosen, for the minute cavities in the interstices are concerned, and these can only be closed by the crushing or flowing of the individual mineral particles. Upon the one hand it is natural to suppose that some of the minerals composing rocks are stronger than any rock. Upon the other hand the cavities may be largely closed by the flowage or fracture of the weaker minerals of a given rock. However this may be, for the purposes of the present discussion it is plain that sandstones are to be placed upon the same basis as quartzites, and possibly shales upon the same basis as slates and schists.

The specific gravity of the outer crust of the earth is assumed to be 2.7.[1] As openings in the earth are usually filled with water, in obtaining a maximum depth at which cavities can exist permanently, it is probably necessary to suppose that cavities are supported by the hydrostatic pressure of a column of water reaching to the surface, and therefore that 1 should be subtracted from the specific gravity of the rock in determining the depth at which the closing of cavities occurs. Under the slowly acting orogenic forces it is probable that the water must be

[1] This estimate of 2.7 was kindly furnished me by Mr. G. K. GILBERT as a close approximation to the specific gravity of the continental masses. It is the same as my own best guess of the specific gravity of the pre-Cambrian rocks.

considered as free to escape, and that the viscosity of water in minute crevices plays no part.

If it be supposed that the rocks above the cavities are solid to the surface, and therefore that they are not supported by the hydrostatic pressure of a column of water to the surface, the problem is reduced by Professor Hoskins' solution to finding the height of a column 1 square centimeter in area, with a specific gravity of 2.7, which weighs two-thirds of 1700 kilograms for Conclusion I., and weighs 1700 kilograms for Conclusion III. This gives for I. about 4200 meters; for III. about 6300 meters.

If the more probable supposition be made, that the rocks are porous, and therefore that the cavities are supported by the hydrostatic pressure of a column of water extending to the surface, it is necessary to subtract 1 from the specific gravity of the rocks, and the effective pressure is 1.7 grams per cubic centimeter. Applying Professor Hoskins' solution, the question is reduced to finding the height of a column 1 square centimeter in area, with a specific gravity of 1.7, which weighs two-thirds of 1700 kilograms for Conclusion I., and weighs 1700 kilograms for Conclusion III. This gives for I., 6667 meters, and for III., 10,000 meters. For the very strongest rocks the above numbers should perhaps be increased by one-fifth, and this gives a maximum of 12,000 meters.

These conclusions do not apply to rock-inclosed, liquid-filled cavities. So far as one can understand the conditions, such cavities might exist at an indefinite depth, or at least to a depth where the liquid and rock may be miscible in all proportions.

The above numbers fall within the various limits—roughly, 2 to 8 miles—assigned for the "level of no strain,"[1] or as it should perhaps be called more properly the level of no lateral stress, and thus make it probable that the lateral stress is less than the vertical stress of gravity. Therefore it is probable that the conditions upon which Conclusion III. are based more nearly represent the truth for the greater part of the earth

[1] *Manual of Geology*, by JAMES D DANA, 4th ed., 1895, pp. 384, 385.

than do those of Conclusion I. However, in mountain-making regions the lateral stress may be so great as to comply with the conditions of Conclusion I., and therefore cavities may close at the minimum depth.

The maximum result reached by the calculation is probably in excess of the truth, for all of the assumptions excepting that concerning the free escape of water are those favorable to requiring a great depth for the closing of cavities. However, it is believed that the result is valuable, because it is certainly large enough, and we may be sure that at depths greater than 12,000 meters no cavities can exist. Also it is reasonably certain that in the weaker rocks cavities are closed much nearer the surface than this. As more accurate data for the solution of the problem become available, it may be possible to obtain reasonably accurate results for the rocks of greatest strength and also for weaker rocks of different kinds. For instance, if the crushing strength of ice be determined for temperatures at and somewhat below zero centigrade, the greatest possible depth to which crevasses in glaciers extend at such temperatures may be readily calculated.

It is highly probable that the very greatly increased plasticity of rocks when saturated with superheated water, due to the rise of temperature with depth, would lead to the closing of the deeper lying crevices by flowage and welding rather than by fracture. If the increase in temperature is 1° C. for 30 meters, at a depth of 10,000 meters, the material would have a temperature of 333° C. above the average temperature of the level where climate produces no influence. To this, in mountain-making regions, would have to be added any increase in temperature due to dynamic action. Under gravity alone rocks at such a depth would be subjected to a vertical pressure of 2550 kilograms per square centimeter. As has been seen, the lateral pressure might be less than this if the rock was not in mountain-making areas and near the level of no lateral stress, or it might be as much or more than this if in mountain-making areas and therefore subjected to great lateral pressure. It is probable that at

such temperatures and pressures even brittle rocks, under these great and very slowing acting forces, when saturated with superheated water, obey the laws of hydrostatics, for plastic solids when strained beyond the limit of elasticity follow the same laws of deformation as do liquids. It is probable that the above considerations should reduce the estimate for the closing of cavities in the strongest rocks to 10,000 meters or less.

It therefore appears highly probable that at a depth of 10,000 meters not only do no crevices permanently exist in the earth, but the rocks are in such a condition that actual welding of the fractured parts would soon take place, supposing fracture to occur.

Such was apparently the case in the deepest lying gneisses and anorthosites of the original Laurentian area, described by Adams.[1] Here in certain areas each of the individual mineral particles is broken into many fragments. No extraneous or infiltrated material is discovered between the granules, and yet the rocks are exceedingly strong and tough, showing in all probability that the broken particles were welded. However, there may possibly be a zone in which the deformation occurs by minute fractures of the individual particles, these being held together without interspaces, and yet where the temperature and pressure are not sufficient to cause welding.

The conclusions as to the depth at which cavities close accord well with observations in the field and with the microscope. It is only in material from the cores of great mountain masses or in regions subjected to vast denudation that the microscope is unable to discover crevices caused by great deformation. The large secondary cracks and crevices which may have formed during the time when the rocks were nearing the surface by denudation are not here referred to, but the innumerable minute crevices affecting the individual grains, which were plainly produced by the deep-seated deformation of the rock. In many instances in which such crevices are found it appears probable from the geology of the region that the rocks were buried under

[1] A Further Contribution to our Knowledge of the Laurentian, by FRANK D. ADAMS. Am. Jour. Sci. (3), Vol. L., 1895, pp. 62, 63.

well-nigh 10,000 meters of material, although this is difficult to demonstrate.

Whether rocks flow or fracture is in many cases largely dependent on the rapidity of deformation. As pointed out by Professor Hoskins, a rock under a certain pressure in two directions, when rapidly deformed by a greater pressure in a third direction, may be fractured, and when less rapidly deformed may flow. This results from the fact that the elastic limit of a rock is always less than its ultimate strength. During the time of rapid deformation the rock may be fractured and crevices and cracks formed which are subsequently closed by plastic flow even if the stresses decrease in amount. Also, as the stresses were slowly increasing, there may have been very considerable flowage before any fractures were produced. Hence, even in homogeneous rocks, the zone of fracture and the zone of flowage are not sharply separated from each other, and the upper part of the zone of flowage is at different depths under varying conditions of stress. This principle is illustrated by the distortion of rocks in ancient buildings and by slabs of marble suspended by their ends in cemeteries.[1] This latter case shows how important the element of time is in the deformation of rocks, and that, given a sufficient time, a stress much below the ultimate strength may surpass the elastic limit and result in flowage. It thus becomes clear that there may be a very considerable thickness for any given rock in which it may be in the zone of fracture or in the zone of flowage, depending upon the amount of differential stress.

(3) *Rocks buried to such a depth that the weight of the superincumbent strata exceeds their ultimate strength are in the zone of plasticity and flowage.* These are the conditions of folding, for permanent perfect flexure is possible only by flowage of material. It is a contradiction to suppose that cracks and crevices can form under these conditions. Were it possible for an opening to be made in any way, under the hypothesis the rock would

[1] An Illustration of the Flexibility of Limestone, by ARTHUR WINSLOW. Am. Jour. Sci. (3), Vol. XLIII., 1892, pp. 133, 134.

flow toward the opening and close it. All of the rocks concerned are everywhere under compressive stress. The material at any given moment, when deformed, moves from places of great compression to places of less compression. In other words, there is always a tendency for the rocks to approach equilibrium through the forces applied, or to obey the laws of hydrostatics. In order that deformation shall occur, the difference between the greatest and the least stresses must equal or surpass the elastic limit of the rock in question under the conditions in which it exists. In rocks which were bent when so deeply buried that no cracks or crevices could form even temporarily, it is probable that the material flowed to its new position quietly, without shock, under the enormous stress to which it was subjected.[1]

Even if in the zone of flowage, the relative thickness and strength of the members folded will play their part. If the mass were exactly homogeneous it would flow in the direction of least resistance, like a mass of tallow. But the rock masses are heterogeneous, and the alternating layers of different plasticity may retain their individuality, there being no considerable commingling of the materials of one layer with the materials of others. The strong, thick beds will greatly vary the direction of movement of the material at a given place, and thus, as explained by Willis, develop folds of great length and amplitude. On account of their relatively resistant character when bent into anticlines and synclines, the anticlines will be able to carry part of the superincumbent load, and thus relieve to some extent the softer beds below, which however, as a consequence, promptly flow in the direction of relief or least resistance and ever press against the confining arch, and thus do their part, which may be the major part, of carrying the superincumbent load. In a similar manner

[1] The manner of the molecular rearrangement by which flowage is accomplished will not here be discussed. In some cases of extreme deformation the granulation or even the recrystallization of the rock is complete. In intermediate cases strain effects are usually marked. For the present purposes we are concerned with the larger deformation of the rock masses. Even were the deformation accomplished wholly by minute fractures without crevices, the deformation in mass, would appear to be that of a plastic body.

the strong formations bent into synclines because of the thrust ransmitted along their limbs furnished in part by the weight carried by the adjacent anticlines, will give increased pressure to the softer beds below and add to the ordinary thrust which is already forcing the material to follow the arches of the adjacent anticlines. However, if the superincumbent strata be but sufficient, the strongest and most brittle rock beds, such as quartzite and jaspilite, may be crumpled or bent upon themselves within their own radius without macroscopic sign of crevice or fracture. In extreme cases the microscope is unable to detect any evidence of crevices or cracks, but it shows in a most remarkable manner that the mineral particles have been greatly flattened.

The thinner and softer the beds the less potent are they to control the movement of any considerable amount of material. Therefore, under given conditions, the thinner and softer the beds the shorter and the steeper are the folds, and more nearly does their material approach in its movement to the flowage of tallow. In soft homogeneous shales the approximation is closest. Therefore, in a series or group of beds of different lithological characters, the thick, strong beds are less closely folded than the thin, weak beds. The softer layers are greatly thickened here and greatly thinned there, as demanded by the stronger layers. The folding of the first may be comparatively simple, and the second may be closely plicated. These principles are finely illustrated in the Hiwassee section of the Ocoee series of the southern Appalachians.

In any great anticlinorium, even if the strongest rock be at the bottom — for instance, a massif of granite — it yields to the force of thrust under the law of normal plastic flow, moving toward the places of least compression, and ever presses against and helps to raise and support the overlying arch of sedimentary and other rock. If a massif were absolutely homogeneous without reference to its strength, its movements would be analogous to that of wax. Consequent upon such movement, as explained in a subsequent paper, it is believed that uniform cleavage is often produced. But no massif is homogeneous. It is composed of

mineral particles of different kinds and of different sizes. In a larger way it is composed of rock masses of different characters. Frequently these masses of different characters and strength are divided by vertical or steeply inclined planes of weakness, rather than horizontal ones, as in the sedimentary rocks; hence, major movements take place along the major inclined planes and minor movements along minor planes and between the mineral particles. Complex minor folding and shearing therefore occur in the readjustment of a massif to its new position. The major planes of shearing may be called fault planes, but they differ from ordinary faults in that the parts moved over one another are always in close contact, and probably are also always welded.

When a set of rock beds are bent even slightly, readjustment and rearrangment of the material must occur to some extent, and the amount increases in proportion as the rocks are closely folded.

If a steel bar be bent the molecules are separated to some extent upon the convex side and compressed upon the concave side. When released from stress the bar, by virtue of elasticity, springs back to its original position. While to some slight degree rocks are elastic when subjected to forces continuing for a short time, it may be doubted whether this property is of importance in considering the slowly acting and long-continued forces of rock folding, except perhaps in the slight flexures of great extent. Single rock beds, when much deformed, are rather to be compared to a wrought-iron bar, which when bent takes a permanent set. In this case there is an actual flowage of material or rearrangement of the particles to meet the new conditions. The half of the bar on the convex side subjected to tension is lengthened, and, to compensate, it is of less cross-section then originally. The half of the bar on the concave side subjected to compression is shortened, and, to compensate, it is of greater cross-section than originally. Each homogeneous rock stratum when bent acts like the iron bar to a certain extent. There is rearrangement of its material to new positions, and when the bending occurs without fracture the movements of the rock particles may be like those of the par-

ticles of the compressed part of the iron bar. But rock beds are usually composed of different mineral constituents, which differ from one another in strength, in hardness, in brittleness, in elasticity, and in size. The necessary rearrangement of the mineral particles more largely affects the weak, small particles than the large, strong ones. However, as shown by microscopical study, where a district is closely folded, no particle of a rock stratum, small or great, simple or complex, weak or strong,

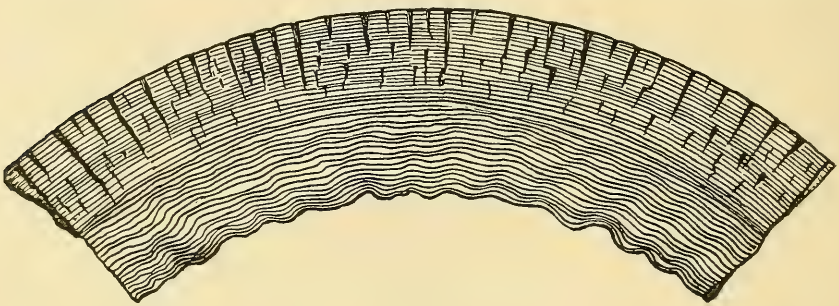


FIG. 1.

escapes the effects of, or fails to take part in, the necessary readjustment of folding.

If a rock stratum could be bent without fracture in such a position that the superincumbent weight were slight, about one-half of the bed, like the iron bar, would be elongated, and the other half would be compressed. Between the two there would be a neutral plane.

As rock beds are brittle they act differently from an iron bar when bent to any considerable degree. Beginning at the middle of the mass in the trough or crest of the fold and passing toward the convex surface, the first lamina is under tension, the second under greater tension, and so on, each stratum being stretched more than the preceding. The tensile force may go beyond the limit of elasticity and radial cracks be formed. (Fig. 1.) Beginning again at the center and passing toward the concave surface, the first layer is under compression, the second under greater compression, and so on, each stratum being more severely squeezed

than the preceding. This may go beyond the limit of elasticity and produce minor plications.

But the majority of strata which have been closely folded when bent were deeply buried beneath other strata. If the superincumbent weight was greater than the strength of the rock all parts of it were under compression, increasing, it is true, from top to bottom in an anticline, and if the mass is not too thick from bottom to top in a syncline. In this case there was no

FIG. 2.

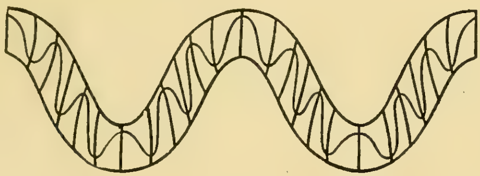


FIG. 3.

neutral plane. The rearrangements which took place were therefore those of varying compression,—flowage away from the places of greatest compression and flowage toward the places of least compression. The crenulations in an anticline may mean that the part of the fold seen was in the compressed area, the stretched and fractured part being removed by erosion. Where both the anticlines and synclines show plications throughout, it follows that the superincumbent strata were so thick that no zone of stretching could be formed, the weight being beyond the supporting strength of the rocks, and the movements being those of a heterogeneous plastic body.

Just as there is rearrangement of the particles within a bed, so there is readjustment of the beds over one another. This may be illustrated by a bunch of paper. (Figs. 2 and 3.) If straight lines be drawn at the edges of a bunch of horizontal sheets, and then the whole be bent into folds, it will be found that the straight lines become curved. In other words, the sheets were moved over one another. An examination of the curved lines

shows that on opposite sides of an anticline or syncline the movement for any given stratum is in opposite directions. Therefore at the anticlines and synclines the forces are directly opposed and hence the stretching or plications at these places, as already explained. But on the limbs of the folds the forces are in the same direction for each lamina, but in opposite directions for laminæ upon opposite sides of any layer, thus constituting a couple. Each stratum moves up as compared with the one next below it, and each stratum moves down as compared with the one next above it. In the case of much inclined and overturned folds this statement needs modification.

The axial lines also show that on the crests of the anticlines and in the troughs of the synclines there was comparatively little movement, while at the middle of the limbs of the folds movements were at a maximum. From this experiment and from Figs. 4 and 5 we would expect that in folded rock strata the effects of readjustment would be least at the crests of the anticlines and troughs of the synclines and most at the middle of the limbs, and such are the facts. In a subsequent article it will be seen that clastic rocks become crystalline in proportion to the degree of shearing and the intensity of the pressure. The former is at a maximum on the limbs of folds and at a minimum on the crests and troughs. Further, secondary structures may develop on the limbs nearly parallel to the beds, while upon the anticlines and synclines the secondary structures form across the beds. It follows that on the anticlines and synclines, where there is most crenulation and puckering of the laminæ, the original structures are less altered, and the clastic characters in sediments, such as sandstones and conglomerates, are likely to be preserved. Upon the other hand, upon the limbs of the folds the obliteration of fragmental characters may be complete. We therefore have the paradox that where there is most crenulation there is least metamorphism; where least crenulation, most metamorphism. This of course applies only to the different positions of the rock in a fold, not to a gently folded district as compared with a more closely folded area.

But the rock beds as they occur in nature differ from the bunch of paper in that they are of varying thickness and strength. The major readjustments of the rock beds occur between the thick and strong strata, and within the weak and soft strata. In these latter, therefore, the rearrangement of the particles is far more profound than would be the case if such beds were folded alone. In closely folded districts among other evidence of readjustments the polishing effects of accommodation between the beds may always be seen in the slickensided surfaces of the major and stronger beds, and in cases of complicated folding the same phenomena are observable between the thinnest laminæ. A most striking instance of this polishing is seen in the Jura Mountains, where at many places both sides of the strong, thick layers of Jurassic limestone are polished as smoothly as if glaciated. They reflect the sun like an imperfect mirror. At some places where the folds are steep, layers have fallen down along these movement planes, exposing great surfaces of beautifully polished rock. In the folded Cambrian quartzites of Doe River, Tennessee, the polishing of the layers by accommodation is scarcely less strikingly illustrated.

If a given bed in the center of a rock formation be plicated and the layers above and below be folded in a strictly parallel manner, in passing away from the central bed in either direction those on either side are less closely folded, and finally the crenulations become slight. If the folds are close in the center they die out with great rapidity. The above follows directly from the laws of deformation of solid masses, and is illustrated by Fig. 4. It should be observed that the more crenulated lines are longer than the less crenulated ones. In so far as this is imitated in nature this implies that there is differential movement between the layers, for originally all of the beds must be supposed to have been of the same length. Such differential motion doubtless does occur in strata in which the folds differ in character, for the more closely folded beds must be subjected to severer thrusts or have been originally weaker, so that the thrust is more effective, or have been in a position in

which friction gave less resisting power. The ideal figure probably more nearly illustrates the effects of nature in passing downward from the central line than in passing upward, for the deformation in superficial strata may be accomplished by jointing, faulting, and brecciation.

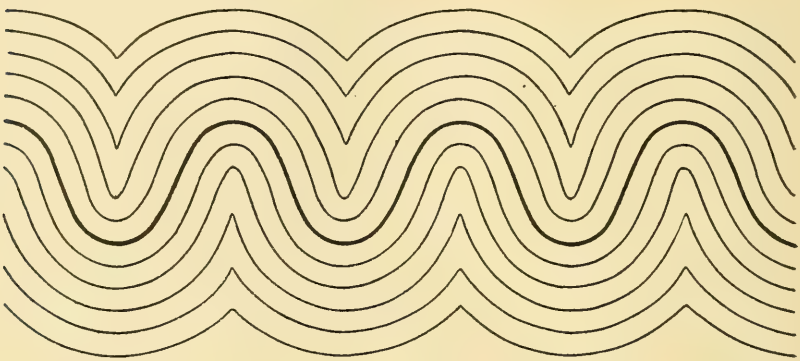


FIG. 4.

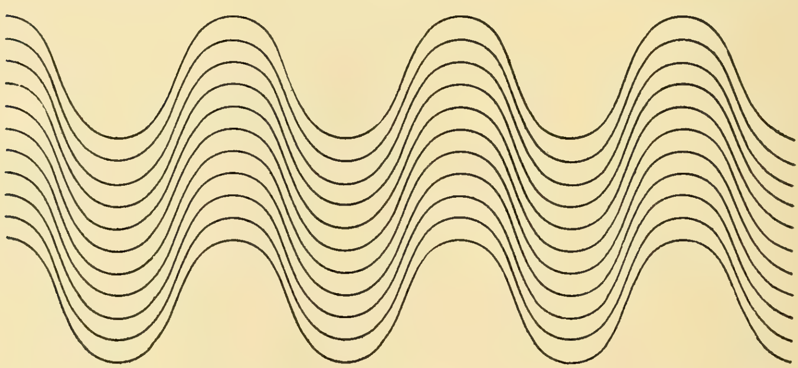


FIG. 5.

If beds above and below the central one be folded in a similar fashion, the limbs of the different layers will be closely pressed together or thinned, or both, and at the anticlines and synclines there will be spaces between the layers, or thickening, or both (Fig. 5). But this result can only be accomplished by plastic flow of the material of the limbs toward the areas of relief. This often produces minor plications at the crests and troughs. Even where the folding is only moderately close the limbs of folds

may be only one-half as thick as the troughs and crests. Where the folding is very close the troughs and crests must be several times as thick as the limbs in order that they may have similar forms.

It is evident from the above that close folds can persist in depth with similar forms only by great differential movement of material, for the readjustment will only go so far as demanded by the differential stresses. It is therefore to be expected that the close folds of mountain districts die out rapidly with increasing depth. This would certainly be true if the lateral stresses diminish, as they must do if the theory of "level of no strain" at very moderate depth be correct. The foregoing doubtless partly explains the open folding often observed in the center of the mountain masses as contrasted with the closely folded flanks, although in many cases other causes undoubtedly enter.

This rapid disappearance of folds with increased depth is beautifully illustrated in a section along the Schuylkill River near Philadelphia, between Lafayette and Spring Mill, shown me by Miss Florence Bascom. In the center of the section is gently undulating gneiss. In passing toward the outer part of the gneiss it is closely folded. The gneiss is flanked on either side by still more closely folded mica-schist. Not only is the principle illustrated by the entire section, but at various places close local folds may be seen, above and below which the folds rapidly become more open. The same is illustrated in the crumpled gneisses of the Ottawa River. The same principle is illustrated upon a much larger scale by the section along the Doe River west from Cranberry, N. C. The folding and the schistosity of the pre-Cambrian granitoid gneisses are gently composite, while the overlying Palæozoic quartzite shows many close minor folds. This case is a particularly good one, for it can hardly be supposed that the quartzite is much less rigid than the gneissoid granite.

It follows from the above that where different beds are in folds of similar forms rearrangement within the beds, adjustment between the beds, and distortion of the beds all work together

to shear the limbs of the folds parallel to the bedding and to develop plications in the crowns and troughs.

(2) *Since the boundary between the zone of fracture and the zone of flowage is at a different depth for two rocks of unequal strength, and for the same rock under different conditions of stress, there is a zone of combined fracture and flowage.* In a set of heterogeneous beds upper weak strata may be in the zone of folding, while lower and stronger strata may be in the zone of fracture. Also, as pointed out by Willis, if strong folded strata at anticlines are competent to carry much of the load, as they often are if the arches are not too long, weaker strata below may be so relieved from weight as to be partly deformed by fracture. Thus between the horizon where all the rocks of a district fracture, notwithstanding the weight of the superincumbent beds and the horizon where the effective weight of the superincumbent beds, is so great that no rock fractures is a zone of combined folding and fracturing. This central zone is one of great thickness, and is of the first importance.

A soft shale may be in the zone of folding, far above a strong quartzite or jaspilite, and the latter be in the zone of partial deformation by fracture. This difference in strength is at many places certainly equal to the weight of 2000 or 3000 meters of strata, and is probably equal to the weight of 5000 or more meters of strata. Thus this middle zone is probably at least 5000 meters thick, and it may be considerably thicker than this.

In heterogeneous rock strata in this middle zone, irregular fracturing, brecciation, jointing, faulting, folding and the development of secondary structure may occur together in a most complex manner. A deeply buried, brittle formation may be under such stress that as a whole it folds without major fracturing, but in a minor way it may be faulted, fractured, or brecciated. The fracturing may leave no permanent openings, as the softer material may promptly flow and fill the openings between the more brittle broken layers. Such is the case in the jaspilite beds of the Lower Marquette series of Michigan. Such is also the case at many places where beds of shale or limestone

are interstratified with beds of grit or sandstone. The first may pass to its new position by homogeneous flow, the second by repeated fractures, which in extreme cases may break the harder beds into fragments and bury them in the softer rocks. The same relations often are seen between mobile marble and brittle gneiss. Whether fracturing always implies at least temporary crevices is an undetermined point.

The weight of the superincumbent material may have been so great that the rock beds as a whole bent without macroscopic fracture, and yet the microscope may show that the individual grains were broken and that minute crevices were formed which have been subsequently filled by secondary infiltrations. At many places the massive beds the quartzites of Doe River, Tennessee, are bent upon themselves within their own radius, with no macroscopic evidence of crevice or fracture. But the microscope shows that the fracturing and resultant flattening of the quartz grains was almost universal.

This illustration shows that for a given kind of rock the zone of fracture passes gradually into the zone of flowage. Even where so deeply buried that all large fractures are absent and the rocks are practically in the zone of flowage, the microscope may still show crevices. It has already been indicated that the zone of flowage is much deeper for some rocks than for others. Also for the same rock mass it may be less deep when gently folded than when closely folded. It is therefore clear that there are gradations between the three zones—of fracturing, of fracturing and flowage, and of flowage. In the placing of a rock mass in one of the three zones it is to be considered as belonging to the one to which it most closely corresponds. If the rocks are everywhere broken and show comparatively little folding, they are in the zone of fracture; if they show much fracturing and also are folded, they are in the zone of fracture and flowage; if the fractures are subordinate or microscopic, they are in the zone of flowage.

C. R. VanHise.

EDITORIAL.

A CARD recently sent out by the director of the United States Geological Survey contains this announcement: "The following provision was included in an act of congress, approved March 2, 1895: '*Provided*, That hereafter the report of the mineral resources of the United States shall be issued as a part of the report of the director of the Geological Survey.'"

This change in the form of the mineral resources serves as an excuse for some reflections upon the subject of the sizes of geological publications in general. It is to be presumed that the reasons for changing the form of this particular publication are good and sufficient: this is not questioned; and the specific mention of these books must not be regarded as personal, but simply as illustrations of what we believe to be a general principle, applicable to all, or nearly all, geological literature alike. It may be added that the forms of all the publications of the United States Geological Survey are prescribed by statute, and the determination of their sizes is not an individual function of the director.

Our plea is for smaller books. We look upon bookmaking, not as an end or an art, but simply as a means—as a method of recording and conveying information. From the point of view of the bookmaker and the book fancier this may be all wrong, and the rankest of Philistinism for anything we know, but with their view of the matter we have but little to do. No doubt the sizes of books on geology as upon other subjects have been handed down to us. Parkinson's *Organic Remains*, published in three volumes from 1804 to 1811, and Buckland's *Reliquæ Diluvianæ*, were quartos printed in "English"—the size larger than pica. The *Transactions of the Geological Society of London*, the first volume of which was published in 1811, were big quartos. Murchi-

son's *Silurian System*, published in 1839, was even larger, as was also his *Geology of Russia* published in 1845. These publications set the pace, as it were, for books of pretension.

In those days no one thought of taking a book on geology into the field with him—they were for use in the library or the laboratory. Nowadays many, probably most, working geologists, mining engineers, consulting geologists, students and instructors, not to mention miners and prospectors, carry, or want to carry, books with them in the field. To all such persons the size of the book to be carried is a matter of importance, and especially so on long or difficult trips when baggage must be light. To them these bungling big volumes, these ponderous tomes, are simply out of the question. And we are of the opinion that the carrying of books into the field ought to be encouraged, and that their being printed in octavo will encourage it and will, at the same time, increase their usefulness and widen their influence.

If the big quartos had any more in them to the page than the octavos they would have that advantage at least, but they do not as a rule. Take for example the annual reports or the monographs of the Geological Survey. The latter are printed in pica, so they contain no more to the page than octavo pages would in long primer. The annual reports are printed in the same type (long primer) and the pages are the same size as those of the bulletin (7.4″ x 4.4″ solid) and the only difference between them is that the heavy annual reports are made quartos by being printed on heavy paper with wide margins.

Compare the weights of the annual reports and the bulletins: Bulletin 71 (octavo), with 744 pages, bound in cloth, weighs two pounds, ten ounces; the ninth annual report, a quarto of 731 pages, weighs seven pounds, six ounces. In other words, the bulletin weighs less than half as much as the annual reports, page for page.

The following advantages are claimed for the large volumes:

1. They admit of large page plates of fossils, maps, or other illustrations, which are not possible with octavos.

We reply: There is no denying that a map or plate shows

to its best advantage when lying open, flat, and unwrinkled. But the single page plates of the quartos can easily, in many cases, be folded across the middle and tipped in, without in the least diminishing their value to those who use the books. In other cases, of small fossils, for example, plates can just as well be made of smaller size. The gain by decrease in the size of the volume far outweighs any inconvenience arising from the folding of maps or plates.

2. When printed on good paper the leaves open properly, while in the octavos they are too rigid.

We reply that it is no serious matter to find flexible thin paper on which good printing can be done.

3. Books to be taken into the field can be cut apart so that the parts wanted can be carried without inconvenience.

We reply. The suggestion that one cut up his book comes from those who have as many copies as they may need at their disposal. The private individual who has to pay for the books and maps, or who has much difficulty in getting them, rarely feels like tearing out maps or a dozen pages from his volume because it is wanted in the field on a certain trip. He will either take the whole book along or leave it behind.

4. Big books look better than little ones.

We are not disposed to discuss the looks of books. The question with which we are concerned at present is one of service to geologists and to tnose who look to us for help. Books made for display—"editions de looks," as Lowell might say, more especially when the form interferes with their usefulness—are not for the serious minded geologist. We do not mean to imply that the appearance of geological books should be altogether disregarded, but simply that their utility should not be sacrificed to the vanity of authors, or to the book's solemn *otium cum dignitate*.

But we go further: We maintain that big books are inconvenient in the library, on account of the room they occupy both upon the shelf and when in use upon the table, and on account of their coming to pieces after a little use. Every

librarian whose cloth-bound quartos are much handled will bear me out in this.

There is no advantage in very large type: it is just as easy to read the long primer used in the bulletins of the United States Geological Survey as it is to read the pica of the monographs.

There is no advantage whatever to a working geologist or to a student for his books to have large pages, wide margins, or to be printed on unnecessarily thick paper. Such books are cumbersome and unwieldly in the library or laboratory without an abundance of table room, and altogether out of the question for the field.

Small books will serve equally well the man in the office or in the field, in camp or on horseback. The taking of books into the field should be encouraged; our laboratory is there, and there is no other place in which a book can render such lively service.

J. C. B.

Reviews.

The Age of the Second Terrace on the Ohio at Brilliant, near Steubenville.—The inquiry raised by Professor Chamberlin, in his comments (Journal of Geology, Vol. IV., pp. 107–112) upon the age of the gravel at Brilliant, Ohio, in which Mr. Huston's discovery of an implement was made, is both pertinent and important, and certainly calls for a more specific statement of my reasons for believing that its deposition was substantially synchronous with that of the 130-foot terrace at the mouth of the Beaver, about fifty miles above it, concerning whose age there is I believe, no question. Of course the only absolute certainty in the case is that at the time of the deposition of the gravel at Brilliant the floods in the Ohio River at that point reached a height something more than eighty feet above the present low-water mark. This the character of the cross-bedding actually demonstrates. The evidence connecting it with the 130-foot terrace at Beaver, while of a more general character, is still, I think, convincing.

In the first place, Professor Chamberlin's remark that there are terraces on the river above and below Brilliant that reach 120 and 130 feet above low water, while the implement-bearing terrace reaches only 80 feet, though literally correct, conveys a false impression without a fuller statement of the facts. The nearest 130-foot terrace above Brilliant is that at Beaver, where a powerful glacial tributary came into the Ohio overloaded with terrace material. From that point down to Brilliant the terrace, though practically continuous on one side or other of the river, gradually diminishes both in height and in coarseness of material, and never rises more than 102 feet above low water until reaching Portsmouth, two or three hundred miles below, where the Muskingum River, the first glacial tributary below Brilliant, joins the Ohio. Here the terrace rises 110 feet, while at Cincinnati, below the junction of the Little Miami, the terrace for the first time jumps again to the 120-foot level. The smaller height of the terrace at Brilliant, therefore, is readily explained without the theory of its having been worked over.

It should be noted, also, that the locality where the implement was found is near the west side of the trough of the river, whose entire width is here fully one mile. This is just one of those positions, therefore, in which we might look for a diminution both in the original height of the terrace and in the coarseness of its material, since all rivers in building up a flood-plain deposit the coarser material near the main current, and consequently build up the plain higher there than on the margins. I see therefore no reason to be shaken in my conviction that the terrace at Brilliant is approximately as old as that of the 130-foot terrace at Beaver, but it is a question to which I trust specific attention will be given by others. G. FREDERICK WRIGHT.

OBERLIN, Ohio, February 15, 1896.

Place is cheerfully given to the foregoing as it is helpful in bringing out more precisely and amply the question of the age of the terrace at Brilliant. It is also helpful in making additionally clear the fact, urged in the review, that the age of the terrace is an open question of interpretation rather than a firm conclusion based upon substantial demonstration. The brief statement of the review was unquestionably inadequate, but its defects were, we think, less favorable to the grounds of doubt urged by the reviewer than to the grounds of belief entertained by the author, as will perhaps appear from further consideration of the case.

A rigorous discussion of the question would necessarily be lengthy and would require data as yet undetermined, but a few of the more obvious considerations necessary to a safe interpretation may be briefly indicated.

The view entertained by Professor Wright that the glacial filling would naturally be highest at the mouths of the main streams which came down from the edge of the ice is not an improbable one, though not necessarily the only one. The conception involves a series of sudden rises in the river bottom at the mouths of the tributaries followed by declines below them; in the present case, a rise to 130 feet at the mouth of the Beaver River; a decline down stream to some unknown level below 80 feet; another rise to 110 feet at the mouth of the Muskingum River, a second decline, and again a rise to 120 feet near the mouth of the Little Miami. The case is really more complicated than this, because it involves the deposits of the Scioto, Great Miami and minor streams, but this is immaterial for present purposes.

Now what would be the normal history of a stream bed filled in this rythmical fashion, when the source of special supply was cut off? Obviously erosion must have begun on the crests of the high deposits. The material so eroded must have been carried forward and *deposited in the lower stretches* just as material is now being deposited in the bottom of Lake Pepin, whose existence is attributed to the deposits of the Chippewa River that enters just below it. Clearly the eroded material could not be carried over the next rise until a common degradation gradient for the whole section was established. A period, therefore, followed the close of the glacial action during which the high deposits were cut down and *the low deposits built up.* In the present case the Beaver deposits were presumably cut down and the Brilliant deposits built up.

How long this period continued it is impossible to estimate accurately, for it was dependent on several uncertain conditions. (1) From the very nature of the hypothesis, it is impossible to determine what was the status of filling of the low parts at the close of glacial action. Almost any degree of filling or lack of filling may be assumed. (2) The retarding effects of the Champlain depression are quite unknown. (3) The deposits in the valleys of the glacial tributaries participated in the action to an undetermined degree. As soon as the high deposits at their mouths began to be cut down, their gradients, already high, would be increased and their material would be carried into the main stream and would check further degradation until it was disposed of. It was even possible, under certain conditions, for these tributaries to continue to build up the deposits at their mouths after the cessation of glacial action.

How much the Brilliant terrace was built up during the establishment of a common plane of degradation seems to be quite indeterminable. Taking the present Ohio as a basis of reference, and supposing the surface of the Brilliant terrace to represent the plane of equation (neither of which is beyond question) there were heights of 30 to 50 feet, in addition to the contributions of the tributaries, to be brought down, and the low parts to be built up from unknown depths. The shallow depth of the implement, eight feet, seems a very modest figure to assign as the possible, or even probable, upbuilding of the Brilliant deposits.

There is still another item in the history. After the establishment of the plane had been accomplished, there was a temporary stage of equilibrium in the parts built up, followed by the initial stages of

degradation. In the degradation of such a plane the material is not taken up once for all and carried out to the sea (except of course that held in suspension), but is shifted little by little through cutting here and filling there, until, piece by piece and shift by shift through almost endless repetitions, the material is at length transferred to the sea. The newly formed portions of the equated plane would be liable to suffer this process over their whole surface during the stage of equilibrium and the early stages of degradation. It would be only when the degradation of the portions down stream had increased the gradient to such an extent as to lead to a contraction of the channel and the abandonment of a portion of the flood plane, that reworking of the surface parts would cease.

If, therefore, we assume the style of fluvio-glacial deposition postulated by Professor Wright, we find definite reasons for regarding the upper part of the Brilliant deposit as postglacial in origin, and find moreover special conditions that may have subjected it to reworking during the early stages of degradation that followed its construction. If, on the other hand, we assume that the glacio-fluvial deposits took the form of a common aggradation plane at the close of glacial action, the presumption is that the Brilliant terrace was carved out much later. It is just possible that the Brilliant deposits happened to be at the pivotal point between degradation and filling, and so were original—and the review admitted that they might be—but the more the case is studied the less probable this seems.

T. C. C.

North American Fossil Crinoidea Camerata. By CHARLES WACHSMUTH and FRANK SPRINGER. (Memoirs Museum of Comparative Zoölogy.) Two parts, 800 pages, and atlas of 83 plates. Cambridge, 1895.

During the decade just passed our knowledge of ancient organisms has been enormously expanded, not so much through the old grooves of endless multiplication of species, as along lines in which the most recent conceptions of morphological inquiry are taken into consideration; or along lines having a direct bearing upon the interpretation of geological phenomena. Hence the differentiation of modern palæontology has been chiefly in two directions, and these departments are becoming so widely divergent that they will ere long, if some energetic steps are not taken to prevent it, cease to be of mutual aid. The

science as originally inaugurated was the foundation of modern stratigraphical geology; but of recent years the biological interest has developed so rapidly with the vast accumulations of remains of ancient organic life that this branch of the subject bids fair to soon cut loose entirely from the parent stem. No better illustration of this tendency has been shown than at a late gathering of the principal scientific societies of America. Of all the palæontological papers presented at the meetings not a single one was read before the Geological Society; the entire list was discussed at the biological associations.

The impetus given to palæontology in the direction of pure biology is timely, and the delay in entering that field may be ascribed chiefly to lack of sufficient and proper material for satisfactory study. The palæontologists of the new school have taken up the discussion of live organisms and their examination according to the latest and most approved methods in order that the long extinct forms of life might be interpreted more correctly. And the most advanced students of existing beings are beginning to look with less aversion than formerly to the fossils for the missing links for a complete phylogeny and ontogeny of living things. As the result of it all the value of organic remains for solving the intricate problems of the stratigraphic geology will be increased a hundredfold. The exhilarating effects have already begun to be felt in that branch of geological inquiry that was thought to be all but inert.

The life and racial histories of fossil vertebrates have for some time past yielded most beautiful and suggestive results. In the same direction the vastly more extensive groups of the invertebrate has in this country at least received scarcely a thought. Palæontologists therefore will hail with delight the appearance of Wachsmuth and Springer's masterly and exhaustive monograph on the North American camerata the most important branch of the crinoids. While it is first of all morphological from the foundation up, and the product of inquiries more thoroughly grounded in biological philosophy than any other work perhaps that has ever been issued on the fossil invertebrates in this country, it is also of such high utility in stratigraphy, especially in the great Mississippi basin, that it may be truly said no other one work has ever furnished so valuable criteria for the purposes of correct correlation of geological formations.

Of all fossil remains none are more admirably adapted for morphological study than those of the echinoderms. On account of their

abundance, their peculiarities in geographic and geologic distribution, and their structure, the stalked feather stars or stone-lilies are preëminent. With the skeletal parts composed of regular plates or ossicles, definitely grouped and frequently highly sculptured, all structural changes are readily deciphered.

The work on the crinoids is the outgrowth of studies begun more than twenty years ago, under the encouragement of Louis Agassiz, and prosecuted without intermission ever since. The entire work as contemplated will form two huge quarto volumes, of which the first, in two parts with an atlas of plates, has just been issued. Of the text there are nearly 800 pages; and the plates number 83, comprising 1500 illustrations artistically reproduced as photogravures. In the present installment—the Crinoidea Camerata—there are three main subdivisions; introductory, morphological and descriptive.

The introduction embraces an historical résumé of opinion and a full explanation of the terminology employed in description. Special attention should be called to the clear and concise definitions given of the various structural parts. The terms should be universally adopted as they form by far the best collection ever proposed. American writers especially will need no appeal to at once use them not only to secure uniformity in nomenclature but precision of description. Heretofore the names of the various plates or groups of ossicles have been used in a rather haphazard way. Not only have different designations been given to the same part, but the same title has been repeatedly applied to structures widely separated morphologically.

The morphological part contains the full discussion of the data upon which the entire classification of the crinoids rest, of the genetic relationships of the various groups, and of the structural characteristics.

The plates in general are separated into "Primary" and "Supplementary" pieces. The former occur in every crinoid and comprise the ossicles represented in the early larva, the basals, the infrabasals, the various plates of the rays or arms, the orals, and the joints of the stem. The supplementary pieces, which make their appearance in the more advanced stages, but which are altogether unrepresented in some groups, comprise the remaining plates. The primary ossicles belong either to the "abactinal" or to the "actinal" system. Those of the former including all the plates, connected with the chambered organ and axial cords; the others comprising those communicating with the mouth and the annular vessels surrounding it.

The stem is much more important than generally considered. It is composed of *nodal* and *internodal* joints, and continually increases in length in the growing crinoid by the production of new joints. The nodal plates in the Inadunata, Camerata, and a few of the Mesozoic and recent crinoids, are introduced directly beneath the proximal plate of the calyx, so that the uppermost joint for the time being, is the youngest joint of the stem. In the young Comatula, however, in which the top joint subsequently develops into a controversal, in the Mesozoic Millerocrinus and Apiocrinus, in the recent Rhizocrinus and Calamocrinus, and in all Ichthyocrinidae, forms in which the top joint in the early larva anchylose with the infrabasals, the new nodals are introduced below the top joint. The internodals are interposed between the nodal joints and increase continually in a downward direction during the life of the organisms *pari passu* with the formation of new nodal pieces. The stem matures from the root up, and remains permanently in a state of immaturity at its upper end. The maximum number of internodal joints varies among different forms. Sometimes there are many to the internode, as in the case of most species of Platycrinus, in Mespilocrinus and Rhizocrinus : sometimes only a very few ; while Rhodocrinus, throughout its stem generally, has but one.

The cirri in Palæozoic crinoids are, as a rule, more formidable than in later forms, and in most of them they are confined to the lower part of the stem, often occurring only at the distal end. They are given off from the nodal joints, and are generally arranged singly, rarely in whorls as in recent forms.

It has been the general opinion that all Palæocrinoids are fixed forms, but this view is not now believed to be true. The facts appear to lead to the conclusion that at least many of the species in the later part of life were free for a portion of the time, as in the case of the recent Pentacrinidæ, in which the stem at some time at or near the maturity becomes separated from the root. The terminal end in most of the old crinoids tapers to a sharp point, but a root is rarely attached, while detached roots are found abundantly, but scarcely ever associated in the same stratum with the crown.

The real morphological relations of the Basals and Infrabasals is of particular interest. The latter term is adopted for the first plates in the base, and "basals" for the circlet next to radials. The basals of dicyclic crinoids always consist of five pieces; the infrabasals of five, rarely three. In monocyclic forms the base is divided into five, four,

three and two pieces, or all five plates may be anchylosed, so as to form a single piece. Among the Camerata five basals are restricted to the Lower Silurian forms, four basals to those from the Upper Silurian and Devonian, three to those from Upper Silurian to the Lower Carboniferous, and two in only some forms from the Carboniferous. The diminution in number takes place in geological succession, and is the result of fusion of two or more of the original five plates, as is clearly seen in genera without an anal plate between the radials. In forms, however, in which an anal plate is represented and the basal disk is consequently changed from a pentagonal to hexagonal shape the case is somewhat more complicated, for a bisection of the plates in the hexagonal base would produce six basals instead of five. The introduction of the anal among all the monocyclic groups is accompanied with an increase in the size of one of the basals, there being no special basi-anal plate. In the tripartite base, the smaller plate — always the left antero-lateral one — doubles its size. In the quadripartite base the increase is towards the right of the posterior plate; while in the bisected base in which the left postero-lateral basal, the antero-lateral, and the anterior one are fused, the two plates of the opposite side increase in size so as to correspond with the compound plate to the left. In dicyclic crinoids the introduction of the anal does not affect the arrangement of the infrabasals, and only slightly the form of the basals. In species with three infrabasals, one of the plates is always only one-half the size of the other two. This ossicle is, in the Ichthyocrinidæ and comatula larva directed toward the right posterior radial; but in the Inadunata its position is not constant. The basals of dicyclic crinoids are but little affected by the presence of the anal, only the upper angle of the posterior plate being slightly truncated.

When it was discovered several years ago, by Wachsmuth and Springer that among Palæocrinidæ there is a regular alternation of the successive parts below the radials it was also found that the orientation of the stem in the monocyclic groups is reversed in dicyclic forms. In the former the sharp outer angles of the stem are radial; in the latter interradial. The central canal and the cirri are interradial in the first mentioned forms, but radial in others. The law is, however, applicable to its full extent only in species with pentangular or pentapartite stems, but it is concluded from analogy that the circular stem, wherever it occurs is also practically interradial in dicyclic crinoids and radial in monocyclic ones. However, on applying the rule to mesozoic and later

crinoidæ it appears that in most of the so-called monocyclic forms, the orientation of the stem, central canal, and cirri agrees with the dicyclic type, the infrabasals being succeeded by a radial stem, as in those crinoids in which these plates are present but too small to be visible on account of being completely covered by the upper stem joint. Upon the strength of these observations, partly, these authors suggested that such forms either had small infrabasals hidden beneath the top stem joint, or those pieces had been represented in the larva. Other observations led to the same conclusion. In Extracrinus and in two species of Millericrinus, the former belonging to the Pentacrinidæ, the latter to the Apiocrinidæ, two of the principal families of the Pseudo-monocyclia, small infrabasals actually exist, and it appears very improbable that those plates should be present in genera of the same family, and even among species of the same genus, and absent in others, especially when the space which in some of them is occupied by small infrabasals, is vacant in others, and interradially disposed instead of radially as it would be if the space represented the axial canal. On applying these observations to the Comatulæ it was found that the outer angles of the top stem joint in the Pentacrinoid larva of the Antedon, and the angles of the centrodorsal in the mature animal, did not come under the rules laid down for the Monocyclica, and this led to the conclusion that the Comatulæ also were built upon the dicyclic plan, and had infrabasals in early life. The predictions, which had been based exclusively upon palæontological evidence were afterwards verified by the observations of Bury, who actually found infrabasals in the ciliated larva of Antedon. They consist of three unequal pieces, which in the Pentacrinoid stage are fused together with the top joint, so as to form with the latter one large plate with the five angles radial in position. A similar fusion evidently takes place among palæozoic Ichthyocrinidæ, in which the infrabasals are also coalesced with the upper stem joint, as is shown by specimens in which the stem is detached from the crown. These individuals are in the same condition morphologically, as the two species of Millericrinus figured by de Loriol, in which the infrabasals coalesce with the stem contrary to the other species of that genus, and allied forms having the infrabasals more or less completely fused with the top joint. As this structure prevents the formation of new joints directly beneath the calyx, it is contended, from the analogy, that in all forms in which the infrabasals coalesce with the stem, the new stem plates are introduced at some

point beneath the top joint. The case is quite different in the Pentacrinidæ, where the youngest joint for the time being is the upper joint of the stem. Of the genera referred to this family, Extracrinus has small infrabasals persistent through life; while in Pentacrinus and Metacrinus no trace of these plates can be found in the adult; their stems are disposed interradially as in Extracrinus and other true dicyclic forms. That the plates are fused with the upper stem joint, is scarcely possible, as it would prevent the formation of new joints at the top; it is more probable as indicated by palæontological evidence that the infrabasals within the group, gradually diminished in size, and finally disappeared altogether. The structure of the Pentacrinidæ in this respect is very different from that of the Apiocrinidæ and Comatulæ, and it appears that crinoids in which the upper stem joint is the youngest, cannot be derived from types in which the upper joint is fused with the infrabasals. The latter therefore should be placed near the Ichythyocrinidæ and the Pentacrinidæ with, or close to the Inadunata.

These generalizations, so far as now known, meet with but two exceptions: the axial canal in the stem of Pentacrinus, contrary to that of Metacrinus and Extracrinus is interradially disposed; that of the monocyclic *Glyptocrinus fornshelli*, unlike that of the other species of the same genus, radially, so that the direction of the canals corresponds with the angles of the stem instead of alternating with them. This however does not invalidate the law, but simply points to the existence of the transition forms between the monocyclica and the dicyclica, as must have occurred at some time in the developmental history of the two groups if the one was evolved from the other.

The radials are less complicated in their morphological relations than the plates which they succeed. The term is now restricted to the first plate of each ray; and all succeeding pieces in a radial direction, whether free or incorporated into the calyx, are called brachials. In the earlier Inadunata and articulata but not in the Camerata so far as observed, the radials are frequently compound, being constructed of two segments, united by a horizontal suture, which in the organization of the crinoid corresponds to one plate. In most of the genera having compound radials the double ossicles, the two sections of which are called "infraradial" and "superradial," are confined to the right posterior ray, but they occur also in other rays but never in more than three, two of the radials at least being simple.

Recognizing the radials as practically a single plate in each ray, all plates above must be regarded as brachials to which pinnules may be attached. The terms costals, distichals and palmars are appropriately applied to the first, second and third orders of brachials respectively. When there are further divisions in the rays, the plates are designated as postpalmars, or as brachials of the fourth and fifth orders, and so on. A discrimination is also made between fixed and free brachials, the latter often being termed the arms. The arms are composed of one or two rows of plates. All biserial arms are uniserial in the young crinoid and gradually enter the biserial stage by an interlocking of the joints from opposite sides. In most of the families belonging to the Camerata the uniserial type is restricted to the Silurian, except in Hexacrinitæ. Among the Inadunata biserial arms occur only in a few genera found in the Kaskaskia, in the Coal Measures and in the Trias, but associated with the forms having the uniserial type. All Articulata, palæozoic as well as neozoic have uniserial brachial appendages.

The pinnules in a general way are repetitions of the arms on a small scale. When represented they spring alternately on opposite sides from every second joint and every joint bears a pinnule except in cases of a syzygy, in which the syzygyial plates must be counted in the alternation of the pinnules as one ossicle. Syzygies occur among Palæozoic crinoids either in successive series throughout the arm, as in the Heterocrinidæ and Belemnocrinidæ, or there is but one syzygy to each order of brachials, formed by the two proximal plates, as in Poteriocrinus, Dichocrinus, and in most species of Platycrinus. In Dichocrinus the various orders of brachials to the last axillary consist of two plates each, the first non-pinnulate, the upper bearing an arm instead of a pinnule. A similar arrangement occurs above the costals in most species of Platycrinus and it is quite evident that the plates in question, as in Dichocrinus for example, do form a syzygy. This, however, is not the case is such forms as *Platycrinus huntsvillæ* and a few other species. Here the first pinnule is given off from the proximal distichal, and the second on the same side from the first palmar. It shows clearly that the arm partakes of the alternation of the pinnules, and suggests that the armlets are enlarged pinnules. This is shown more conclusively by the structure of *Glyptocrinus dyeri*. While in most species of Glyptocrinus the second bifurcation takes place from the second distichial, that plate in *G. dyeri* gives off in place of an arm a large pinnule, more than twice as large as an ordinary one, which bending outward

forms an angle as in the case of a true bifurcation. The second pinnule, which is somewhat smaller starts off from the fourth distichial on the opposite side as in the other species of the genus. All succeeding pinnules are small, and are given off alternately from successive joints.

The oral plates have been the subject of much controversy, but their identification in the different groups is now pretty well established. According to Wachsmuth and Springer the orals are not always represented in the adult. When present they surround the mouth or cover it. They may occupy the whole face of the ventral disk or only its median portion. In the former case they rest upon the edges of the radials; in the latter against the perisome. In crinoids with a regular pentamerous symmetry they consist of five pieces interradially disposed, and form the center of the disk. When the symmetry is irregular they are pushed more or less to the anterior side. The former condition prevails among recent crinoids; the latter is the general rule among palæozoic forms. When asymmetrical, the posterior oral by the encroachment of the anal plates, is pushed between the four others, so as to attain a more or less central position. The plate is generally larger than the other four. The orals in all groups in which they are represented consist of five pieces. There is no such thing as an orocentral plate, as some writers have supposed. In some instances the orals seem to be wholly or partly resorbed; the former condition probbly is the case among the Camerata, the latter in certain species of the Fistulata. In regard to the Ambulacra it is now generally admitted that the aperture in the tegmen of palæozoic crinoids is not the oral opening but the anus, and the mouth is subtegminal forming the center of radiation, which, however, is not necessarily the geometrical center. The ambulacra follow the grooves along the ventral side of the arms, and extend from the tips of the pinnules to the mouth. Their inner ends are either exposed upon the disk, or covered wholly or in part by plates of the tegmen. The upper face of the ambulacra is occupied by the food grooves, which are roofed over by the covering plates and frequently are boarded by side pieces. In recent crinoids the covering plates are movable from the tips of the pinnules to the entrance to the mouth; but in most palæozoic ones those of the disk are rigid, so far as known, often heavier, and larger than the intervening plates. The disk portions of the ambulacra in the Camerata, if tegminal form a component part of the tegmen, their plates being suturally connected with one another and with surrounding plates; those

in the Fistulata rest upon the edges of large interradial pieces. When the ambulacra are subtegminal they enter the calyx by the arm openings, and follow the inner floor to the proximity of the mouth.

The "supplementary plates" comprise all calcareous particles between the basals and orals, and between the rays and their subdivisions. They are interradial, interaxillary or anal. The interradial plates which are separated into interbrachials and interambulacrals, comprise all pieces between the basals and orals interradially disposed, the former being confined to the dorsal cup ; the interambulacrals occupy only the spaces between the ambulacra. The interaxillaries, which consist of the interdistichals and interpalmers are located within the axils of the second and third orders of brachials respectively. The anal plates are restricted to the posterior interradial area, and support the anal tube. Another system of supplementary plates occurs in the acrocrinidæ, between the basals and radials. In groups in which the arms are not entirely free from above the radials, the lower arm plates are incorporated into the calyx by means of interbrachials ; and the orals are carried inward toward the actinal center by interambulacrals. The supplementary plates increase in number in the growing crinoid. They are undeveloped in the early larva and in the Laviformiæ. In the Fistulata they are represented only in the tegmen, except in the case of the anal piece. The plates vary exceedingly in form and character, being in some groups well developed and rigid, in others irregular and imperfectly formed or mere lime particles within soft tissues. The great variation in the structure of the plates formerly led to the belief that the rigid and regularly arranged pieces, so characteristic of the Camerata, did not belong to the same system as the irregular small pieces which unite the rays in recent form. A distinction was also made between the ossicles of the tegmen. The heavy, rigid components of the palæozoic forms called "vault" pieces the irregular smaller ones "disk" plates ; and it was supposed that many of the older crinoids had a vault with a disk underneath. That they had two integuments was believed to be indicated by the condition of the ambulacra, which in recent crinoids are exposed, while in palæozoic types they are either completely subtegminal, or the food grooves are rigidly closed by immovable covering pieces. This supposition, however, has proved to be an illusion and to be based upon inaccurate observation. Even in species of Batocrinus and Dorycrinus, in which deception seemed to be almost impossible, it is ascertained from excellent material, that the

tegmen consists of but one set of ossicles and that the plates are suturally connected and solid on the outside, but perforated and vesicular within. The condition of the ambulacra in camerate crinoids, whether tegminal or subtegminal, does not represent an essential structural feature, but is a natural consequence of differences in the form and construction of the tegmen in the respective groups and as such cannot be of much value from a morphological or classificatory point of view. Subtegminal ambulacra, as a rule, are most prevalent in species with high dome and bulging arm basis; while forms with a flat or depressed ventral surface generally have tegminal ambulacra. The two styles occur side by side among species of the same genus, and there exist all possible transition forms between the two extremes, *i. e.*, specimens in which the ambulacra are subtegminal at the median portions of the disk, and tegminal near the periphery. By comparing the younger individuals with the older, it appears that the covering of the ambulacra is produced in the growing animal by the gradual extension of the interambulacral areas along the lines of the ambulacra, either completely covering them, or leaving the portions next to the arm basis exposed. The ambulacra of the Camerata, therefore, are covered not by an element unrepresented in other groups, but by small superimposed plates passing out from the disk proper. These plates were quite small in the Silurian species, but change essentially until in the Carboniferous they frequently attain the large size and rigidness of the other plates in the tegmen. As to the closure of the mouth, it is now believed that it was subsequent to the introduction of the anal plate, by means of which the posterior oral was pushed in between the four others so as to close the opening.

The interbrachials and interambulacrals, in most of the Camerata, pass insensibly into one another, there being no line of demarkation by which they may be separated, except that produced by the arms, and it is difficult to understand how these plates can be distinct structures as is generally supposed. That their morphological relations are very close is conclusively shown by the fact that the very same plates which in the Actinocrinidæ and Batocrinidæ are strictly interbrachial, are in the Platycrinidæ and Hexacrindidæ partly interbrachial and partly interambulacral, and in the Cyathocrinidæ exclusively interambulacral. That the plates of the two hemispheres occasionally are interrupted, notably in Batocrinus, Catocrinus and Strocrinus, is readily explained by the large increase that here takes place in the number of arms, which prevents the development of interbrachials around the arm bases.

Essentially different is the ventral structure of the Fistulata, which have no interradial plates in the dorsal cup, the anal plate excepted, but which have these pieces extensively developed in the tegmen. Four of the interambulacral spaces are raised but little above the level of the arm bases, while the posterior area is extended abruptly upward, and is formed into a tube or sac of variable shape and size, rising beyond the tips of the arms. This sac, which may be regarded as a greatly extended anal area, probably lodged a large portion of the visceral mass. The sac is generally composed of longitudinal rows of hexagonal plates, and is often perforated by pores. The structure at the four other sides of the disk is rarely observed except among the Cyathocrinidæ in which it is probably more substantial than in other groups. In Cyathocrinus there are six plates, interradially disposed, resting against the inflected upper edges of the radials, the lateral margins being covered by the ambulacra. Four of them are large and of equal size, the two others, lying at the posterior side, are quite narrow and enclose a madreporite. The margins of the larger plates are roofed over in perfect specimens by numerous small irregular pieces, while the perforated plate is exposed to view.

Most of the Ichthyocrinidæ have interbrachial plates, which in some forms are large and massive, in others small; some are arranged regularly, others irregularly, but all are movable. The plates of the tegmen are very minute and irregularly arranged, the ambulacra are tegminal, and the mouth and food grooves are open. Thus there is among palæozoic crinoids a tegmen having all the characteristics of the disk in recent species, demonstrating conclusively that the disk as a ventral structure is not confined to the neocrinoids as generally supposed. Moreover, a careful study of the various tegmens in the different groups shows that there are represented among them all intermediate stages from the simplest disk to the most rigid and complicated "vault" of the Actinocrinidæ, and that the so-called vault is a highly modified form of the disk.

The anal plates bear a most important part in the phylogeny of palæozoic crinoids, and they are among the best criteria for purposes of classification. When present they occupy, in the Camerata, the median line of the posterior area so as to divide the interbrachial plates into two equal sets, and being in rows containing an odd number they have the effect, as it were, of breaking up the middle plate into two, as in cases where no anal plate is inserted between the sections.

The anal plates vary considerably in their position and distribution, and, in some groups are absent altogether. As a rule they are largely represented in species with a stout tube or a lateral opening, and are wanting or are poorly developed when the anus is central.

Among the Fistulata the term "anal plates" has been applied to two ossicles of different origin, the one radial, the other interradial. The latter is the homologue of the first anal of the Camerata, and rests upon the truncated posterior basal. The other which is not a supplementary plate but the lower section of the compound right posterior radial, performs anal functions only in certain genera. When both plates support the ventral sac as in most of the Poteriocrinidæ, the second, which is actually the first or lowest in point of position, is placed obliquely to the right of the other, without disturbing the orientation or the alternate arrangement with the basals. Both plates undergo many modifications, and the various phases as they occur in different geological stages, may be regarded as excellent criteria for generic separation. The earlier Camerata have neither a radi-anal nor a regular anal plate both of which make their appearance with the increasing size of the ventral sac. As this grows larger, the two posterior radials which previously were in contact laterally, part, and the anal piece is introduced to support the sac. Afterwards when the ventral sac attains still greater proportions, the supraradial is shifted to the right in a position almost directly above the right postero-lateral basal, so as to give to the infraradial which retains its place, a rather oblique direction. In the Poteriocrinidæ, in which the lower faces of the costals fill up the whole width of the radials, leaving no room for attachment, the lower plates of the sac enter the calyx. At the close of the Carboniferous, the sac becomes reduced again to its former insignificance, the anal plates generally disappear, and the two posterior radials meet again laterally. This interpretation of the origin of the anal piece (or plate x as it is frequently called) differs essentially from that given by the English writers on the crinoids and particularly by Mr. Bather, who regards the plate as primitively derived from a brachial, which in time passed down from above into the dorsal cup. This author also claims that in the older forms with a compound right-posterior radial, such as in Iocrinus and Heterocrinus, the plate in question is supported by the supraradial and does not touch the infrabasal ; but that, further, in Hybocrinus and Dendrocrinus, it passes down from above the radial and finally rests with its lower half between the two posterior radials,

then being supported partly by the basals and partly by the infraradial; and that in Carabocrinus, Botryocrinus, and allied forms the said ossicle has sunk to a line with the radials. Mr. Bather evidently has confounded here plates which are morphologically quite distinct. In the above genera the plate under consideration is represented only by Dendrocrinus, Carabocrinus, and Botrycrinus. The piece to which reference is made in Iocrinus, Heterocrinus and Hybocrinus is a plate of the vental sac, as is conclusively proven by Dendrocrinus, otherwise it must be admitted that the plate would be represented twice in the same specimen, by the true anal plate which rests upon the basals, and by the tube plate (of Iocrinus) which is supported by the supraradial. The anal area of Dendrocrinus is like that of Poteriocrinus, only that the superradial of the former does not move away from the inferradial, as it does in the latter. This is not necessary in a form like Dendrocrinus in which the arm-facets occupy a comparatively small part of the radials and leave ample space for the support of the tube. In the Poteriocrinidæ, however, in which the upper surface of the radials is taken up completely by the costals, the foundation of the tube is not adequate to the width and the deficiency is manifestly made up by a shifting of the superradial and the introduction of another plate for the support of the tube.

In the anal interradius, as it appears in the various families of the Camerata, a close agreement is found between the anal plate (x) and the tube plates of the Fistulata on one side, and the anal plate and interradials on the other. Admitting this, a more satisfactory explanation of the anal plates of the Fistulata is reached than that given by Mr. Bather whose views do not cover the Camerata; besides being based upon premises which appear to be entirely hypothetical. If it were true that Bather's plate x of Iocrinus passed down in later forms from above the superradial to the basals, it would certainly require a partial revolution of the whole tube; but this is clearly disproved by the structure itself, which throughout its full length is composed of hexangular pieces, regularly arranged in longitudinal rows. Bather also regards the anals of the Camerata as morphologically distinct from those of the Fistulata, while there actually seems to be good grounds for believing that the plate x of the latter is homologous with the first anal in the Camerata, and also with the anal which for a time occurs in the larva of the Comatulæ; but that the Camerata have no radi-anal for the simple reason that they have no compound radials. The anals

of the Icthyocrinidæ are arranged in a similar way to those in the Fistulata. Some of them have only the plate x represented, others only the radi-anal, still others both, and some of them have no anal plate at all. The Larviformia have neither the one nor the other, although they have frequently compound radials. The anal tube where it occurs, is inserted intermediate between the radials and orals.

The systematic arrangement of the crinoids as proposed by Wachsmuth and Springer is one that will require but few material changes for a century to come. Based entirely upon morphological principles, with a completeness and wealth of ontogenetic and phylogenetic data that is rarely obtainable among fossil organisms, the essential elements of classification are more firmly grounded than perhaps in any other group. No attempt in recent years towards a natural and rational orderly arrangement of a large and complex assemblage of organic remains has been so signally successful. Nor has the evolution of the groups in time and space been neglected. For classificatory purposes special emphasis should be placed upon a number of features. Of very great importance is the growth of the stem, whether the young joints are formed beneath the proximal ring of the calyx or beneath the top stem joint. Particular stress is also to be placed on the alternate arrangement of the stem with the lower ring of plates in the calyx, by which it is determined that by far the large majority of the neozoic crinoids are dicyclic and not monocyclic. Of exceptional significance are certain features in the Ichthyocrinidæ which clearly indicate affinities with the Apiocrinidæ, Bourgueticrinidæ, Eugeniacrinidæ, and Comatulæ all five groups of which are placed together among the Articulata. All have a disk composed of small, irregular, and movable pieces, with open mouth and open food grooves, all are dicyclic, but the infrabasals coalesce with the top stem joint, so as to prevent the introduction of new joints directly beneath the calyx. From the Articulata are excluded the Encrinidæ and Pentacrinidæ which are generally arranged with them. The infrabasals of the former of the two families are very small, or are resorbed in the growing animal, but they do not coalesce with the top joint which is therefore for the time being the youngest joint of the stem. The Pentacrinidæ have, through the Encrinidæ, close affinities with the Poterocrinidæ, and probably are their descendants, but if they really belong to the Inadunata as is now believed they represent somewhat abberant types, for the lower brachials take part in the calyx.

Not less important than the morphological contributions to a knowledge of the stemmed echinoderms are the advancements made in their classification, and it is safe to say that the systematic arrangement of the group is now practically settled for a century to come.

The three groups of stalked echinoderms, the cystids, blastoids and crinoids are regarded as orders of equal rank. The forms of the first are earliest in time and lowest in taxonomic position, and may be considered the ancestral types of the other two. The crinoid type itself is a very old one, dating from the Cambrian, in which it was already in a high stage of development. During the Ordovician the cystidian features almost wholly disappeared. The crinoidal group is remarkable for the persistency it has shown in preserving its pentamerous symmetry, and although the introduction of the anal plate was a disturbing element so great as to well-nigh produce a lasting bilateral arrangement, the former type was finally permanently retained.

The two primary groups of crinoids which were formerly almost universally accepted are abandoned. These are the Neocrinoidea and Palæocrinoidea. In their stead are recognized three principal subdivisions: Inadunata, Camerata and Articulata. It is particularly noteworthy that this ternate grouping of the crinoids is essentially the same as Wacksmuth originally proposed more than twenty years ago and that after being compelled by students of the recent forms to abandon it and to substitute others, a final careful survey, in the light of recent discoveries, of all crinoids both living and fossil, has clearly shown that the main subdivisions first suggested are essentially valid and are applicable to all known forms. The criteria for separating the crinoids into orders are briefly:

1. Condition of arms, whether free above the radials, or partly incorporated in the calyx.

2. Mode of union between plates of the calyx, whether movable or rigid.

3. Growth of the stem, whether new plates are formed beneath the proximal ring of the calyx or beneath the top stem joint.

The simplest forms of the Crinoidea Inadunata have the dorsal cup composed invariably of only two circlets of plates or three where infrabasals are present; there are no supplementary ossicles except an anal piece which is however not always present; the arms are free from the radials up. In the construction of the ventral disk two different plans are recognizable and upon these are established two subgroups—

the Larviformia and Fistulata. The former has the disk in its simplest possible form, being made up of five large orals arranged in a pyramid; the second has the ventral side extended into a sac or closed tube, often reaching beyond the ends of the arms.

The Camerata are distinguished by the large number of supplementary pieces which bring the proximal arm plates into the calyx, thus enlarging the visceral cavity. All plates are heavy and immovable and the mouth and food grooves are tightly closed.

The Articulata have to some extent the incorporation of the lower arm plates with the calyx, but the plates are movable instead of rigid. The mouth and food grooves are open. The infrabasals are fused with the top stem joint which is not the youngest plate of the stalk. According to whether or not the pinnules are present two suborders are recognized: the Pinnata and Impinnata.

For the family distinctions the supplementary plates constitute excellent features for classification, and while of small importance physiologically, they form a good example of a truth which is met with everywhere in biology that characters of physiological value are not always of equally great utility for purposes of classification. Of prime import in this regard are the anal pieces.

Of the three groups of crinoids having ordinal rank, that constituting the Camerata is by far the most important. An analysis of the families is briefly as follows:

I. LOWER BRACHIALS AND INTERBRACHIALS FORMING AN IMPORTANT PART OF THE DORSAL CUP.

A. Interradials poorly defined.
Lower plates of rays more or less completely separated from those of other rays and from primary interradials by irregular supplementary pieces; anal interradius divided by a row of conspicuous plates; (dicyclic or monocyclic) .... RETEOCRINIDÆ

B. Interradials well defined.

1. Dicyclic.
   a. Radials in contact, except at the posterior side ..... THYSANOCRINIDÆ
   b. Radials separated all around .... RHODOCRINIDÆ
2. Monocyclic.
   a. Radials in contact all around. Symmetry of the dorsal cup if not strictly pentamerous, disturbed by the introduction of anals between the brachials only .... MELOCRINIDÆ
   Arms borne in compartments formed by partitions attached to tegmen; dorsal cup perfectly pentamerous; plates of calyx limited to a definite number .... CALYPTOCRINIDÆ

b. Radials separated at the posterior side by an anal plate.
First anal plate heptagonal, followed by a second between interbrachials. . . . . BATOCRINIDÆ
First anal plate hexagonal, followed by two interbrachials without a second anal; arms branching from two main trunks by alternate bifurcation. . . . . ACTINOCRINIDÆ

II. BRACHIALS AND INTERBRACHIALS ONLY SLIGHTLY REPRESENTED IN THE DORSAL CUP.

1. Dicyclic.
Radials in contact except at the posterior side . . . . CROTAOCRINIDÆ
2. Monocyclic.
a. Radials in contact all around; base pentagonal. . . . . . . PLATYCRINIDÆ
b. Radials separated on posterior side by an anal plate; base hexagonal. Basals directly followed by the radials. . . . . HEXACRINIDÆ
Basals separated from radials by accessory pieces . . . . ACROCRINIDÆ

While the morphological and classificatory chapters of the monograph on North American crinoids appeal more directly to palæontologists interested in the biological side of the subject, the descriptive part will be of greatest practical value to the stratigraphical geologist. This portion of the work is a complete revision of all Camerata known from this country up to September 1894. Every species is fully and clearly described compared with closely related forms, beautifully illustrated and referred to its proper geological horizon; the full literature of each and the localities where it occurs are also given. All the species have been redescribed from the most perfect material that could be found in all museums and private collections. The liberality shown Wachsmuth and Springer by those persons who possessed suitable specimens in placing them at free disposal is to be commended in the highest terms. It was the means of making accessible nearly all the type specimens known, and in fact, most of the crinoid material in the country. In addition there were the authors' own magnificent collections which contain more than nine-tenths of the known American species and over two-thirds of the European, of which many are represented by scores and even hundreds of individuals. These large collections gave new ideas regarding the limits of the different species and enabled a discrimination to be made between species and varieties, and between the young specimens and the adults, which led to the elimination of a large number previously recognized. The establishment of species on rational morphological grounds and not on trivial superficial or accidental characters which are relatively unimportant as classificatory criteria is a point of excellence which cannot be too highly praised, and one which should

be the central consideration in the revision of the nomenclature of all groups of fossils as well as living organisms. That there has long existed a burdensome and extensive synonomy among crinoidal as well as all other classes of animals no one who has given the subject attention will for a moment question. The most casual consideration has rendered apparent the urgent necessity of a careful and complete revision of nearly all groups. The wide geographical distribution of many species and the concomitant changes of environment may readily be referred to as among the chief causes of local variation in species now living. Among fossil forms, however, there is in addition a greater factor of geological range which must be carefully considered. Notwithstanding the careful and conscientious labors of a large number of writers, little attention has been given in the description of species to these highly important factors which for the most part have been entirely overlooked. But the contributions to synonymy have not originated wholly in the manner mentioned. A still greater number of invalid names have come from a practice which cannot be condemned in terms too severe. It is the tendency to describe species, and genera also, from imperfectly preserved material, often from a single aberrant specimen, without making adequate comparisons with allied forms. This deplorable state of things, which in the natural course of events should be continually getting better with the advance of knowledge, appears of late years to have become so virulent that it is a serious question whether such work should not properly be ignored altogether. It will ever remain one of the crowning glories of Wachsmuth and Springer's efforts that they have shown no sympathy whatever with such work; and that with calm, untrammeled and truly scientific judgment they have relegated to oblivion such a large number of worse than useless specific names which have so long stood as a menace to progress in this field of palæontologic research. A full list of synonyms so far as they apply to the Camerata is given.

The preparation of the monograph occupied over seven years of continuous work, but this gives but a faint idea of the vast amount of labor involved. This work will be indispensable to all future writers on crinoids, as well as to the collector in the identification of his material. It embraces the whole literature on the subject and thus dispenses with dozens of papers which are not accessible to the student. Besides it has the great advantage that the same terms are used throughout the whole work, and that these terms are clearly and accurately

defined. The identification of the forms is facilitated by analytic tables for families and genera; and the species are arranged under the various genera in such a way that those most closely related are placed near one another. There is a general index, and an index of the authors quoted.

CHARLES R. KEYES.

En resa till norra ishafvet sommaren 1892, företagen med understöd af vegastipendiet. [A Journey to the Arctic Ocean during the Summer 1892, made with the aid of the Vega Stipend.] By AXEL HAMBERG. Reprint from Ymer, 1894.

The author accompanied a Norwegian sealer visiting Beeren Island and the Spitzbergen Islands. In King's Bay a stay of several days was made, and the author studied some ice fields, which he named Lovèns névés. On the surface of the ice at this place but few small lateral moraines were to be seen, but in a fracture of the ice an inner moraine was observed. This consisted of about ten strata of assorted gravel and sand alternating with layers of ice. It was evidently a medial moraine in the lee of a projecting low mountain top, seen several miles inland. It is stated that similar features are common in the ice fields of these arctic islands. The author suggests that, if the ice were melted away, such moraines would give rise to structures much resembling åsar, both as to the contained material and as to the form and direction of the resulting topography. At one place some of these deposits were seen extending a distance at right angles away from the ice margin and resembling somewhat the Scottish kames. The névés were composed of bedded ice, in some places extending out in the sea. In several instances it had been melted away under the water and marginal blocks had evidently been detached by their own weight, leaving the edge of the ice standing in vertical smooth walls as if "cut off with a knife."

A number of photographs were taken with a camera fitted for photogrammetric measurements and a map constructed from these photographs accompanies the paper. The névés represented on this map are seen to occupy valleys among several small groups of hills and extending to within less than a mile from the shore. The front edge of the ice sometimes forms an evenly rounded curve and sometimes a vertical cliff from 60 to 100 feet high. It is suggested that this difference in the behavior of the terminal edge (when resting on the land) may be due to a difference in the morainic material of the

ice. The vertical escarpments could not here have been formed by the breaking-off of any blocks, for no such were in view. They may have been made, or they may at least be maintained in their present attitude by the difference in the motion of the upper and lower layers of the ice, the lower strata being held back by friction with the ground, and the higher pushing out over them. It is intimated that such behavior of the superimposed layers was observed.

The stratification of the ice was everywhere marked. Sometimes the layers were folded. In one of the illustrations of the paper an S-shaped bending of the strata occurs where the ice is forced up over the moraine in front. In another place cracks are shown running at right angles with the lamination of the ice. Sometimes there were veins (of clear ice?) branching and extending in various directions. One of these veins was over a meter in thickness. These veins seemed to have been formed by running water and are an indication of the internal conditions of temperature.

The morainic material of the ice consists of intercalated thin layers above. Next to the ground these layers are sometimes three feet in thickness. A lenticular mass is shown in one illustration, where the weight of the inclosed material has flexed the layers below in an even curve. With the exception of the lowest layers of the moraine its material is believed to have come from the nunataks, which rise through the ice. These are subject to intense weathering from frost, the detached material sliding down on the ice and becoming imbedded in it, as it forms from the falling snow. No striated bowlders were observed, but there was a great deal of rounded as well as of angular material. The surface of the rounded bowlders was seen to be covered by a fine powder. Even the bowlders in the upper layers of the ice are well rounded. The author's observations support the view that the intercalated layers of morainic material are planes of shearing, where the material is rolled between two layers of ice of relatively different rate of horizontal progression. The shearing within each stratum of ice is probably quite insignificant. It is regarded as likely that the mode of motion in a névé of stratified ice is in this respect essentially different from that in homogeneous glacier ice.

With a few exceptions the névés seen near King's Bay appear to be advancing. In one instance the edge of the ice was seen rising on the rear slope of a moraine in front. This is referred to as a proof that a névé may be caused to have an ascending current by a horizontal

thrust from behind. The glacial features seen in King's Bay are particularly interesting for the close resemblance they bear to those observed by Professor Chamberlin in Greenland. J. A. UDDEN.

Palæontographia Italica. Memorie di paleontologia. Pubblicate per cura del PROFESSOR MARIO CANAVARI. Vol. I., 1895, Pisa, 1896.

This is a new palæontological publication modeled on the *Palæontographica* of Germany, whose purpose is to unite in a central organ for leading memoirs on the fossils of Italy. The first number is an ample and interesting volume of 275 pages and eighteen lithograph plates.

The first paper is by C. F. Parona on "Nuove osservazioni sopra la fauna e l'età degli strati con *Posidonomya alpina* nei Lette Comuni," pp. 1–42, Plates I. and II.; it is a continuation of Parona's monograph "I fossili degli strati a *Pos. alpina* di Camporovere nei Lette Comuni" Atti della Soc. di Lei. Nat. Milano, Vol. XXIII., 1880. In the present paper the author has described and listed a large fauna of the Middle or Brown Jura, most of the species being new, only a few of the familiar names of Quenstedt's, Oppel's, and Sowerby's species appearing among them.

The paper by A. Tommasi, "La Fauna del Trias inferiore nel versante meridionale delle Alpi," pp. 43–76, Plates III. and IV., describes fifty-three species, of which eight are new. The entire fauna consists of one brachiopod, thirty-four pelecypods, eleven gasterpods, and seven cephalopods, all ammonites but one.

The third paper of the volume is by Antonio Neviani, "Briozoi fossili della Farnesina e Monte Mario presso Roma, pp. 77–140, Plates V. and VI. The author describes one hundred and ten species and varieties of Tertiary Bryozoa, of which about three-fourths are still living in the Mediterranean and adjacent seas. Useful and interesting notes on distribution in space and depth are also given.

The fourth paper is by C. Fornasini, on "Foraminiferi della marna del Vaticano," p. 141–148, Plate VII. In this short space twenty-three species are described and listed, although none are new.

The fifth paper is by V. Simonelli, "Gli antozoi pliocenici del Ponticello di Savena presso Bologna," pp. 149–168, Plate VIII. Twenty-three species of Pliocene corals are described, many of which are still living in the Mediterranean and Atlantic waters.

The next paper is that of Francesco Bassani, "La Ittiofauna della Dolomia principale di Giffoni (Prov. Salerno)," pp. 169–210, Plates

IX.–XV. From the Trias, Bassani describes eleven species, representing eight genera, and five families.

The most important memoir of the volume is that of Vinassa de Regny, "Synopsis dei molluschi terziari delle Alpi venete, Parte prima; Strati con Velates Schmiedeliana," pp. 210–275, Plates XVI., XVIII. Heretofore papers on Italian Tertiary geology have been badly scattered and hard to get at, but de Regny's memoir will help to remove this difficulty by republishing in accessible form many obscure figures and descriptions.

All the papers in Volume I. of the *Palæontographia Italica* are well indexed, and have copious bibliographic lists appended, an example that other palæontological publications might well follow. J. P. S.

The Soil; its Nature, Relations, and Fundamental Principles of Management. Pp. xv.+ 303, illustrated. By F. H. King. New York, 1895.

This little book was written for students of agriculture, but it contains so much of interest to students of geology that we give it room here.

The distinctly geological matter in the volume is well chosen, and the geological illustrations are all helpful and to the point. The following topics are of especial interest to geologists: origin of soils, methods of rock disintegration, sediments moved by streams, work of rain, composition of soils, nitrogen of the soil, capillarity, solution and osmosis, soil water, distribution of roots in the soil, relations of air to soil.

One of the commendable virtues of the book is the simplicity of the writer's style: complex problems of chemistry, physics, geology, and botany are all dealt with in the simplest manner possible. There is no laborious argumentation to bewilder the new student. The occasional dropping into poetry will strike the critical as rather overdoing the matter perhaps, but there is nothing to detract from the dignity of the subject under consideration.

It is to be hoped that the author of this valuable little book will soon give the world the benefit of his more technical knowledge of the physics and chemistry of soils expressed in his clear, easy style, and accompanied with the references needed by advance students and investigators.

Aside from the value such a work may have for agriculture, it will aid geologists to understand the work of water and acids in the alteration of minerals and rocks, the agencies of rock decomposition and the formation and modification of many ore deposits. J. C. B.

Authors' Abstracts.

The Loess of Western Illinois and Southeastern Iowa. By Frank Leverett, Denmark, Iowa.

The north border of the loess both in western Illinois and eastern Iowa appears to have been determined by the ice-sheet. The loess is apparently an apron of silt spread out to the south by water issuing from the ice-sheet. It is loose textured at the north and becomes finer textured toward the south, showing a decrease in the strength of depositing currents. The wide extent of the loess over the uplands has led to a consideration of the influence of the wind as well as water in its distribution. It is thought that wind-deposited loess may be distinguished from that which is water-deposited. The wide extent, however, appears to be due to water-distribution rather than wind. Wind action apparently came into force subsequent to the water distribution and is of minor importance.

Possible Depth of Mining and Boring. Alfred C. Lane. Geol. Society of America, Philadelphia, 1895.

The paper was prepared for the forthcoming volume of *Mineral Industry*. The possible depth of mining was studied from the construction of a curve representing the minimum cost of mining at various depths. The chief factors in increasing the cost were found to be the increased length of time required for a hoist, and the increasing temperature. Stress was laid on the efficiency of the escape of compressed air in neutralizing the increasing rock temperature, and the rate of increase in temperature in the Lake Superior copper mines was discussed, with the result that an increase in temperature of not more than 1° F. in 100 feet could safely be assumed and that in all probability a depth of 10,000 feet could be reached without insuperable difficulty. A shaft is now down 4800 feet, and another one started which will not reach the lode until it is down 5000 feet. In the discussion following Professor Shaler suggested that the low temperature gradient might be due to the cooling effect of the use of compressed air in the mines, and Mr. Lane suggested that it might also be due to a

rise in the surface temperature since glacial times, and suggested that the Wheeling record indicated that, or it might also be due to the cooling effect of downward percolating waters. He urged the advantage of an exploratory boring from the bottom of one of these shafts which might thus penetrate nearly 15,000 feet into the earth's crust.

The Soils of Texas. By E. T. DUMBLE. Texas Academy of Science, 1895, pp. 60 and 1 map.

A preliminary classification of Texas soils is offered based upon their geological relations and origin. It is preceded by a brief statement of the general geology and of the main topographic features of the state. This is followed by a general description of the characteristic residual soils of the principal horizons of the various geological formations present. A brief statement is then made as to the characters of the drift soils and a somewhat more extended description of the great body of fertile alluvial soils is given, especial attention being called to those of the Brazos and Rio Grande.

The Yardley Fault. By BENJAMIN SMITH LYMAN. Proc. Am. Phil. Society, Vol. XXXIV., 1895.

A conspicuous normal fault in the railroad cut near Yardley, Bucks county, Pa., had seeming importance from a mistake, through certain optical illusions, in the direction of its dip and downthrow; but a correct geometrical construction shows the displacement to be no more than perhaps twelve feet. The blackish, highly quartzose filling is derived from neighboring gneiss, or still closer sand rock, and not from trap, as once imagined. Small geological and topographical maps of the neighborhood and of the fault, with a cross-section, are given.

The Chalfont Fault Rock, So-called. By BENJAMIN SMITH LYMAN. Proc. Am. Phil. Society, Vol. XXXIV., 1895.

The so-called fault rock of the Chalfont railroad cut, Bucks county, Pa., formerly supposed to fill confusedly a fault 100 feet wide that heaved a nearly vertical trap dike about five miles, is merely much cleaved, somewhat folded, dark shale-beds, dipping seventy degrees, or less, and striking acutely across the railroad. Two photographic views along the strike are given in demonstration.

Crystalline Limestones and Associated Rocks of the Northwestern Adirondack Region. By C. H. Smyth, Jr.

Extensive belts of highly crystalline limestone constitute an important feature of the region. These belts are separated by wide areas of rather massive gneisses, whose origin and relations to the limestone are obscure, and afford the chief problem for future investigation. They are probably largely igneous.

Rocks whose igneous origin has been clearly ascertained are scattered over the whole area. They are chiefly granite, diorite, gabbro and diabase. These are all younger than the limestone, cutting it with typical irruptive contacts, often affording a variety of contact minerals.

The most extensive igneous rock passes into a gneiss which spreads over a wide area and is quite similar to many of the other gneisses. This gives a clue to the origin of the latter. Some of the granites are suggestive in the same direction.

Much crumpling and crushing in the limestone series is indicative of dynamic metamorphism, but should most of the gneisses prove to be intrusive it would strengthen the hypothesis of thermal metamorphism on a large scale.

U. S. Geologic Atlas, Folio 1, Livingston, Montana, 1894.

This folio consists of three and one-fourth pages of text, a topographic sheet (scale 1:250,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving a columnar section. The text is signed by Joseph P. Iddings and Walter H. Weed, geologists, and Arnold Hague, geologist in charge.

The area of country covered by the folio lies between the parallels of latitude 45° and 46° and the meridians 110° and 111°, and embraces 3340 square miles. It is within the state of Montana, including portions of Gallatin and Park counties, and the town of Livingston is within its limits. The region is elevated, the lowest point being over 4000 feet, the major portion over 6000 feet, and the highest peaks over 11,000 feet, above sea level.

The principal topographic features are the Snowy Mountains, Gallatin Range, Bridger Range, Crazy Mountains, and Yellowstone Valley. The Yellowstone River is the main drainage channel for the area. It enters the district from the Yellowstone Park about the middle of the southern border, flows northwest and north through a closed valley thirty miles long and three miles wide, and at Livingston

turns northeast and enters the broad, open valley beyond the frontal ranges of the Rocky Mountains.

The rocks forming the surface of the country are partly crystalline schists, including gneiss schist, with granite and other granular rocks; partly sedimentary formations, including limestone, sandstone, and shales; and partly lavas and other igneous rocks. The crystalline schists are mainly Archean, and constitute a large part of the southern half of the region. They form the high mountains and plateau drained by Boulder River, and those from Emigrant Peak south. A small area of sandstones, conglomerates, slates, and arenaceous limestones occurring in the Bridger Range have been referred to the Algonkian. They lie unconformably upon the crystalline schists, and are overlain unconformably by the Palæozoic series.

The sedimentary formations cover one-half the area, and present a total thickness of 20,000 feet, embracing all the grand divisions of geologic time since the Archean. The chief feature is the great development of the latest Cretaceous strata, which are 12,000 feet thick above the Laramie, the total thickness of the Palæozoic being only 3500 feet. The series from the basal (Flathead) quartzite to and including the Laramie coal beds, is conformable throughout. The Palœozoic strata occur upturned at steep angles against the crystalline schists, or in steep anticlines. The lowest bed is the Flathead quartzite. Above it are shales and limestones of Cambrian age. The Silurian is represented by only a few feet of formation, whose precise age is doubtful. Four hundred and fifty feet of shales and limestones represent the Devonian. The Carboniferous strata are 2000 feet thick. They are here, as elsewhere, the mountain limestones, and form the crest of the Bridger Range and the summits of some peaks of the Snowy Range. The Trias is recognized only in the southern part of the region, as thin belts of red sandstone. The Jura varies considerably in character, being mostly shales and fissile limestones. These two formations are 500 feet thick.

The Cretaceous constitutes more than one-half of the total thickness of strata. Its lowest member is the Dakota conglomerate, with sandstone and some shale. Over this is the Colorado group, including Benton shales and Niobrara limestone, aggregating 1800 feet in thickness. Over this is the Montana group, 1800 feet thick, consisting of Pierre shales and Fox Hills limestone. The Laramie sandstone, with some intercalated clays and beds of coal, is 1000 feet thick. Above

this is a slight unconformity, followed by conglomerates, sandstones, and clays of the Livingston formation, 12,000 feet thick. Near the base the conglomerate consists largely of volcanic material. True tuff-breccia of volcanic rocks occurs intercalated near the base of the series on Boulder River.

Neocene lake beds occur in Gallatin Valley, and on Yellowstone River, opposite Fridley.

Superficial deposits of the Pleistocene period occur as alluvium over all the broader river valleys. Glacial drift, consisting of gravel, sand, and bowlders, is scattered over the higher parts of the country, and covers the Yellowstone Valley south of Chicory.

Igneous rocks occupy a large part of the area of this sheet. They consist of subaërial breccias or agglomerates, with tuffs and lava-flows, and of intrusive bodies, such as dikes, sheets, laccolites, and stocks or necks. They occur extensively in the southeastern corner of the district, and form the Gallatin Range along the southwestern border, and another area east of Boulder River. In the Crazy Mountains the igneous rocks are wholly intrusive. The extrusive rocks are andesitic breccia, acid and basic; trachytic rhyolite, rhyolite, and basalt. The intrusive rocks are gabbro, diorite, theralite, basic and acid porphyries, basic and acid andesites and dacites. Several centers of volcanic eruption, active in early Tertiary time, occur in the region. They are at Emigrant Gulch, Haystack Mountain, and Crazy Mountains. Other centers are just outside of the limits of the atlas sheet.

The chief economic deposits of the district are the gold-bearing gravels of Emigrant, Bear, and Crevice gulches. They have been worked on a small scale. Gold veins occur in Emigrant Gulch, Crevice Gulch, and Haystack Mountain. Copper ores in small quantities have been found at the head of Boulder River and of Slough Creek. Clays serviceable for brick-building occur in the alluvium near Livingston, and in the lake-beds near Bozeman, also in the Cretaceous strata. Two coal fields exist within the district, the Cinnabar field and the Bozeman field. The aggregate thickness of the coal is twelve to eighteen feet, made up of a number of seams, only three of which are workable. The coal is bituminous, of variable character, and in places is a fair coking coal. The output in 1889 was 49,400 tons.

U. S. Geologic Atlas, Folio 3, Placerville, California, 1894.

This folio consists of one and one-half pages of text descriptive of the Gold Belt and one and one-half pages descriptive of the

Placerville district, signed by Waldemar Lindgren and H. W. Turner, geologists, and G. F. Becker, geologist in charge; a topographic map (scale 1 : 125,000) of the district, a sheet showing the areal geology, another showing the economic geology, and a third exhibiting structure sections.

Geography.—The territory represented lies between the meridians 120° 30′ and 121° and the parallels 38° 30′ and 39°, and contains 925 square miles. It is located in the upper foothill region of the Sierra Nevada, the elevation ranging from 300 feet to 5400. The prevailing character of the topography is that of irregular and undulating plateaus cut by deep canyons and steep ravines. The district is drained by the three forks of the American River in the northern part and by the three forks of the Cosumnes River in the southern part.

Geology.—The eastern half of the tract is principally composed of a somewhat metamorphosed sedimentary series, the Calaveras formation, of presumable Carboniferous age. The rocks consist chiefly of clay-slates and quartzitic sandstones, and have in general a northerly strike and steep easterly dip. Several irregular intrusive masses of granitic rocks are contained in the sedimentary series. The western half of the tract is much more complicated. A belt of black slates belonging to the Mariposa formation, or late Jurassic age, traverses the tract from north to south. To the west of this belt follow again sedimentary rocks of the Calaveras formation, greatly cut up by igneous rocks. The sedimentary rocks here, as well as in the western part, have a northerly strike and steep easterly dip. The western part of the area contains a great abundance of basic igneous rocks, consisting of diabase, augite, hornblendic porphyrite, gabbro-diorite, pyroxenite, and serpentine. Over large areas certain of these basic rocks have been converted to amphibolitic schists by dynamo-metamorphic processes. Covering the ridges and resting unconformably on the older rocks are large masses of Neocene effusive rocks, chiefly tuffs and breccias of rhyolite and andesite. These masses form gently sloping tables, underneath which the Neocene gravel channels are found.

Economic geology.—The Neocene river channels, with very highly auriferous gravel, are exposed and mined at several places in the area, for instance, at Todd's Valley, near Georgetown, and in the vicinity of Placerville. Many and important auriferous quartz veins are found in

the area. The principal ones occur along the belt of Mariposa slates previously mentioned, and form the northern end of what is usually referred to as the Mother Lode of California. Passing by Nashville and Placerville, the vein is almost continuous up to the northern part of the area, where it splits up into several branches, which die out before reaching the northern border. Important veins are, however, also found both to the east and west of this belt. Near the eastern line lies the important mining district of Grizzly Flat.

There are practically no alluvial soils in the area. The deep soil on the summit of the ridges is always a residual soil, formed by the decomposition of the rocks in place.

U. S. Geologic Atlas, Folio 5, Sacramento, California, 1849.

This folio consists of one and one-half pages of text descriptive of the Gold Belt and one and one-half pages descriptive of the Sacramento tract, signed by Waldemar Lindgren, geologist, and G. F. Becker, geologist in charge; a topographic map (scale 1 : 125,000) of the tract, a sheet showing the areal geology, another showing the economic geology, and a third exhibiting structure sections.

Topography.—The Sacramento tract includes the territory between the meridians 121° and 121° 30′ and the parallels 38° 30′ and 39°, and contains 925 square miles. The western half of the tract embraces a part of the Sacramento Valley, while the eastern half contains the first foothills of the Sierra Nevada. The elevation ranges from 30 feet above sea level at Sacramento to 2100 feet in the northeastern corner of the tract. The foothill region forms a sloping and undulating table-land, through which the American River has cut a deep and narrow canyon.

Geology.—A small area of sedimentary slates of the Calaveras formation (Carboniferous) occurs in the northeastern corner, and a belt of black clay-slates belonging to the Mariposa formation (late Jurassic) is contained in the igneous rocks of the southeastern part. At Folsom the Mariposa slates are cut off and contact metamorphosed by the granitic rocks of the Rocklin massif. The larger part of the older rocks of this tract is of igneous origin. A large area of diabase and porphyrite is found along the eastern margin. Wide belts of these rocks have been rendered schistose and changed to amphibolites by dynamo-metamorphic processes. Several masses of granodiorite and gabbrodiorite have been intruded into the diabases, porphyrites, and

amphibolites. Small masses of serpentine are sometimes found in the amphibolite; others appear intimately connected with gabbrodiorite.

Superficial flows of andesitic tuffs and breccias cover the older rocks. The larger part of these flows has been eroded. The remaining masses form sloping tables in the lower foothill region. Auriferous gravel channels are found in places below these volcanic rocks. At an elevation of 300 feet the andesite is underlain by clays and sands of the Ione formation, deposited in the gulf which in Neocene times skirted the foothills of the Sierra Nevada. The western part of the tract is largely covered by early Pleistocene deposits of gravel, sand, and hardpan.

Economic geology. Neocene auriferous gravels have been worked to some extent east of Rocklin and south of Auburn. The Pleistocene gravels in the foothills have been very rich in gold, but are now mostly exhausted. At Folsom large masses of Pleistocene gravels are still worked. Auriferous quartz veins have been extensively worked between Ophir and Auburn. Small veins are occasionally worked near Clarksville and in the vicinity of Pilot Hill.

The central mass of granodiorite affords excellent building stone. Limestones occur chiefly as lenses in amphibolite at many places along the eastern border. The soils of the foothill region are residuary in character, while the western part of the tract is occupied by deep alluvial and sedimentary soils.

U. S. Geologic Atlas. Folio 7, Pikes Peak, Montana, 1894.

THIS folio consists of four and-a-half pages of text, signed by Whitman Cross, geologist, a topographical sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, and one of structure sections; followed by a special description of the Cripple Creek mining district, consisting of one page of text on the mining geology, by R. A. F. Penrose, Jr., and a map (scale 1:25,000) showing the economic geology of the district.

Geography.—The district embraces an area of 931.5 square miles, between meridians 105° and 105° 30′ and parallels 38° 30′ and 39°. In its eastern half lies the crest of the granitic Colorado Range, which extends from Manitou Park though Pikes Peak to the southern end of the range, where it sinks to the level of the plains. The western portion of the area is a plateau of granite and volcanic rocks, lying between 8000 and 10,000 feet in elevation, penetrated on the south by deep

canyons of streams tributary to the Arkansas River and by the recess or bay of Garden Park, nearly at the level of the plains. The principal drainage of district is by tributaries of the Arkansas River, which flows through the Royal Gorge just beyond the southern boundary. The remaining drainage is into the Platte River, which cuts across the northwestern corner of the area in a deep canyon.

The Colorado Midland Railroad traverses the district from east to west near its northern boundary. East of the center of the area is the mining district of Cripple Creek, reached by branch railroads from the north and south.

General geology.—The granites of the mountains and plateau regions are reddish in color, coarse or fine grained, and similar to those of many other regions in Colorado. Of special interest is the observation, first made by the survey corps, that these granites contain many large and small fragments of metamorphosed stratified rocks, quartzites and schists, belonging to the oldest series of sedimentary beds, the Algonkian; and hence the granites are not of Archean age, as has previously been assumed. Most, if not all, of the gneisses in this district have been formed from the granites by a shearing strain, as is very clearly demonstrated in many places.

The sedimentary formations of the area, and their characteristics of special interest, may be concisely referred to as follows:

Algonkian.—Nearly 4000 feet of white quartzite, in small part conglomeritic, is shown in the huge inclusion in granite in Wilson Park. These ancient strata are not known in this region except as inclusions.

Silurian.—Three divisions of the Silurian strata, each about 100 feet thick, have been recognized in Garden Park, and named respectively the Manitou limestone, Harding sandstone, and Fremont limestone. The Harding sandstone contains the oldest fossil fishes as yet known. Minor uncomformities separate these formations, and they are not known in so good development elsewhere.

Carboniferous.—Resting on the Silurian is a thin limestone, called the Millsap, carrying a few Carboniferous shells, and known only in small remnants. The red sandstones and grits of Manitou and Garden Parks, 1000 feet in thickness, are considered as of Carboniferous age, and named the Fountain formation. No fossils are known in them.

The strata of the Juratrias and Cretaceous have been found in remnants upon the granite plateau, indicating a former extension of these beds connecting with South Park.

Eocene—The small lake deposit about Florissant is noted the world over for its fossil insects, while fishes, birds, and many plants are also found in these thin beds, which are chiefly made up of volcanic ashes.

The volcanic rocks of the district are numerous and interesting. Those of the western portion belong to a great volcanic center south of South Park. At Cripple Creek is a local volcanic vent the peculiar product of which is the rare rock phonolite.

Many points in the geological history of the Colorado Range have been brought out by the recent survey, such as the evidence of varying relations between land and sea at different periods, shown by unconformities and by remnants of strata on the granite plateau. The shear zones shown by the gneisses, and the observed folds and faults of the foothills, bear directly upon the structural history of this portion of the Rocky Mountains.

Economic geology.—The gold-bearing district of Cripple Creek is directly connected with the volcanic center. The gold ores are free milling near the surface, but pass into telluride smelting ores in depth. They occur in veins, chiefly in the volcanic rocks, but occasionally in the granite near them. The extreme alteration of the rocks of the eruptive center, and the unusual character of the gold veins, have made a detailed study of the mining district necessary. A special topographic and geologic map on the scale $\frac{1}{25000}$, or nearly 2½ inches to the mile, has been made, and the ore deposits have been thoroughly examined by Professor R. A. F. Penrose, Jr.

U. S. Geologic Atlas. Folio 9, Anthracite—Crested Butte, Colorado, 1894.

This double folio consists of three pages of text descriptive of the Elk Mountains, by S. F. Emmons; two pages descriptive of the igneous formations of the two districts, by Whitman Cross; four pages descriptive of the sedimentary formations, by G. H. Eldridge; of each of the two districts a topographic map (scale 1:62500), a map of areal geology, another of economic geology, and a third of structure sections; and finally, a sheet showing a generalized columnar section of the two districts.

Geography.—The combined area represented on the two sheets covers one-eighth of a degree, lying between the parallels 38° 45′ and 39′ and the meridians 106° 45′ and 107° 15′, and is about 27½ miles long from east to west and 17½ from north to south. It includes the southern third of the Elk Mountain group, which lies between the

Sawatch Range on the east and the plateau of the Colorado basin on the west. It is a highly picturesque and mountainous region, and, like the San Juan Mountains to the south, has a more abundant precipitation and is more Alpine in its character than other parts of the Rocky Mountains.

The northern half of the eastern or Crested Butte tract is occupied by the southern portion of the Elk Mountains proper, whose culminating points have an elevation of over 13,000 feet; the southeastern portion of that tract includes the distinct and less elevated Cement Mountain uplift. The rest of this area and the whole of the Anthracite tract is occupied by more or less isolated mountain peaks — Crested Butte, Gothic Mountain, Mount Wheatstone, etc. — and by one prominent north-and-south ridge, the Ruby Range, whose higher summits rise between 12,000 and 13,000 feet above sea level.

The drainage of all this area finds its way through the Gunnison River into the Colorado, and the greater part is carried to the latter stream through the southward-flowing Slate River and its tributaries.

The towns of Crested Butte (9000 feet) and Baldwin (8750 feet), which are near active coal mines, are reached by branches of the Denver and Rio Grande and the Denver and South Park railroads respectively. Other towns higher in the mountains, which were founded by silver miners, are Gothic, Pittsburg, and Irwin. Owing to its great altitude and abundant precipitation, this region is more or less snowbound during eight months of the year, and mining is thereby rendered difficult and costly.

Geological structure.— The most striking feature in the geology of the region is the great development of eruptive rocks which occur as irregular bodies cutting across disturbed and upturned strata; as laccolitic bodies doming up the nearly horizontal strata above a given horizon; as vertical and comparatively narrow dikes; to a limited extent as surface flows; and as a bedded series of breccias, tuffs and conglomerates.

Eruptive activity was most energetic and widespread during the Eocene Tertiary; it continued, however, sporadically, during later periods, the most recent outpourings of lava being probably of Pleistocene age. The principal rock types represented are: in the irregular cross-cutting masses, granite and diorite, and at a later period and in limited areas, rhyolite; the laccolites are mostly of porphyrite, among dike rocks are found diorite, porphyritic diorite, porphyrite, and quartz

porphyry; basalt occurs as a surface flow, and andesitic débris in the tuffs and conglomerates of the bedded series.

Among sedimentary rocks in this region are found representatives of the principal formations from the Archean up to the close of the Mesozoic, with some later formations whose exact age is still somewhat doubtful.

The Cambrian is represented by the Sawatch quartzite, which consists of 50 to 200 feet of white quartzite, conglomeritic at the base, and at certain horizons persistently glauconitic; its fossils are of the Potsdam type.

The Silurian beds, which are locally called the Yule limestone, in an aggregate thickness of 350 to 450 feet consist mainly of limestones, with quartzite at the base and more shaly beds at the top. They contain the same fish remains that characterize the Harding sandstone of the Canyon City section, but organic remains have not been discovered in sufficient abundance to admit of the subdivison of the series on a palæontological basis.

The Carboniferous is represented by three subdivisions. (1) The Leadville limestone, or Lower Carboniferous, has a thickness of 400–525 feet of dark-gray or blue limestones, with some intercalated quartzites and shales. Above this is (2) the Weber formation, which consists of 100–500 feet of shales and limestones, carrying fossils of Coal Measure type. The upper member, known as (3) the Morgan conglomerate, consists mainly, as its name indicates, of conglomerates, which are characterized by the local abundance of pebbles of limestone. It has an observed maximum thickness of 4500 feet, and in its upper portion resembles lithologically the Red Beds, generally assigned to the Trias.

The Juratrias, whose beds are separated from the last mentioned by a great unconformity, is represented by the Gunnison formation, which consists of a heavy white sandstone about 100 feet in thickness, overlain by shales and a little limestone, and carries a fresh-water fauna of supposed Jurassic age.

The Cretaceous is represented by five recognized subdivisions: The Dakota quartzite, 50–300 feet thick; the Benton shale, 150–300 feet thick; the Niobrara limestone, 100–200 feet thick; the Montana formation, comprising the Pierre shales and Fox Hills sandstones, 600–2000 feet thick; the prevailing lithologic characteristics of each of which is indicated by its name. Among later beds are the Ohio

formation, about 200 feet of sandstone and conglomerates; and the Ruby formation, with a maximum thickness of 2500 feet of sandstones, shales, and conglomerates made up to a large extent of eruptive débris. These formations are separated by an unconformity from the underlying Laramie, and to the west of this area pass beneath the beds of the Wasatch Eocene; in the absence of fossil evidence they have been classed as Cretaceous.

The geological structure of this region affords evidence of no less than four important orographic movements, involving the making of new land, the erosion and planing down of the same, and the inauguration of a new cycle of sedimentation, which account for the great variation in thickness of certain formations. First, during post-Archæan time, the first deposits, after which were Upper Cambrian (Sawatch quartzite); second, during Carboniferous time, followed by deposition of Weber shales and Maroon conglomerates; third, during Mesozoic time, followed by deposition of the Gunnison sandstone; and fourth, after Laramie time, followed by the Ohio, Ruby, and Eocene formations.

Mineral resources.—The most important economic product of the region is its coal, which is found in the lower part of the Laramie Cretaceous formation, between beds of sandstone. The quality of the coal varies, according to local conditions more or less favorable to metamorphism, from dry bituminous, through coking coal, to semi-anthracite and anthracite. Next in importance are its silver ores, which occur for the most part in true veins or fault fissures in all varieties of rock, but mainly in the sedimentary beds of upper horizons near eruptive rocks. The ores are generally rich, but in small bodies, and, in consequence of natural obstacles to cheap mining, have not been extensively worked. Gold has been found in paying quantities in the alluvium of a single gulch; lead and copper are accessory products in limited amounts.

THE

JOURNAL OF GEOLOGY

APRIL-MAY, 1896.

THE MAGMATIC ALTERATION OF HORNBLENDE AND BIOTITE.

It is proposed in the following pages, which may be regarded as an elaboration of certain ideas expressed by me a few years ago, to discuss the causes of the well-known "magmatic alteration" or "resorption" of hornblende and biotite, and to suggest the possibility of certain consequences which seem to follow on this alteration[1] and which have an influence on the mineralogical composition of certain rocks.

The alteration of the two minerals in question to a granular mass of augite and magnetite is so well known to every petrographer, and such an excellent detailed description of it may be found in Zirkel's Lehrbuch (I, 716 ff.), that it is unnecessary to devote any space to a description of the facts. It must be recalled, however, that analogous alterations are extremely rare and of doubtful character in the pyroxenic minerals.

The important facts are also to be remembered that the chemical composition of both hornblende and biotite are structurally much more complex than that of the pyroxenes, and that they contain a greater variety of atoms, hydrogen and fluorine being very frequent, if not constant, constituents of both.

It must further be noted that augite is of all minerals one of the easiest to produce artificially either by dry igneous fusion or in other ways, and that melted hornblende invariably crystallizes, under laboratory conditions, as augite. Hornblende and

[1] The word *alteration* as used throughout this paper will be understood to mean only this "magmatic" alteration or "resorption."

biotite, on the contrary, have only been formed artificially in the most recent years. As far as the experiments go they seem to show that the presence of a mineralizing agent (a fluoride or silicofluoride) is necessary for the production of biotite in the dry way, while hornblende has been produced only in the wet way very recently by Chrustschoff. The negative evidence of the experiments points to the conclusion, that for the formation of either biotite or hornblende in an igneous magma pressure is a highly important if not necessary factor, while of no moment in the formation of augite.

CAUSE OF THE ALTERATION.

Current theories.—The theories in vogue to explain the alteration in question follow more or less closely Zirkel's[1] idea of a "caustic chemical action" of the magma on the hornblende and biotite crystals, and suppose either a fusion of the crystals, or their "resorption" (solution) by the surrounding magma and the subsequent crystallization of the augite out of the magma.

In regard to the magnetite there seems to be a difference of opinion, some supposing it to be not dissolved by the magma but crystallizing when the augitic constituents are withdrawn, while others seem to suppose it also to have been dissolved and recrystallized out of the magmatic solution.

These theories postulate an instability of the hornblende and biotite, or at least their instability as regards the solvent power of the magma surrounding them, under surface conditions.

While these various theories differ in details yet they may be discussed together, as the ideas involved in them are much the same and the objections to them are on the whole quite identical.

The current theories rest chiefly on the facts that the alteration proceeds from the outside inward and starts generally from crystal surfaces in contact with the magma; that the chemical composition of the magma has an apparent influence on the alteration, this being much less common in acid than in basic

[1] ZIRKEL Mikroscop. Petrogr. U. S. G. Ex., 40th parallel, VI, 95, 1876.

rocks; that in the most glassy forms of the volcanic rocks the alteration is uncommon; and lastly that melted hornblende recrystallizes as augite.

These arguments are of great weight and will be discussed at greater length later on. Leaving them aside for the present, I would call the reader's attention to a fact often observed which they not only fail to explain but with which they seem to be quite at variance. This is the preservation of the original form of the hornblende or biotite crystal, with its sharp angles and straight edges, in a magma which has been in motion around it, as is shown by the flow structure and fragmentary hornblendes with their fracture surfaces unaltered. That the molten or dissolved zone surrounding the crystal demanded by these theories could possess sufficient cohesion or solidity to preserve its exact original form, unchanged by the, in many cases, powerful disrupting action of the moving magma, is to me quite inconceivable and passes the bounds of reasonable conjecture. Such a zone must be, in the nature of the case, more or less fluid, often as fluid as the surrounding magma, and hence easily subject to all kinds of distortion and disruption by the current. Yet such distortions as are expected are not found. In many cases the exact original form is preserved, and in the cases where the original form is lost the outlines are merely rounded by the removal of the outer portion, and the greater part, or the whole, of the remaining mass is composed of the granular alteration products.

The supposed fusion of the crystals has been accounted for[1] by the rise in temperature of the rock-mass on solidification which is demanded by theory and which has been actually observed.[2] But it has not been shown that the rise in temperature is sufficient for the fusion, nor why such an effect does not take place on the augites, which would destroy any zonal or hourglass structure. Furthermore this hypothesis cannot explain the very numerous cases of alteration which took place while the

[1] Lagorio, Natur d. Glasbasis, Min. Pet. Mitth. VIII, 463, 1887.

[2] Roth. Der Vesuv., Berlin, 1857, 304.

mass was in motion, and hence before solidification—an objection which is fatal.

That resorption of the hornblende or biotite substance may, and does, take place is not to be denied. The occurrence of hornblende and biotite crystals with embayments and irregular outlines, but with no alteration border, shows that here the resorbed substance has been carried off. These cases are exactly analogous to the corrosion phenomena seen in other minerals. It is indeed hard to explain why hornblende and biotite alone should be so favored as to have their substance and form left to them in the majority of cases, while quartz, feldspar, olivine and augite should lose part of their substance on corrosion so that we do not meet with a zone of different composition from their crystals or the groundmass.

The ægirine mantles about many quartzes in the basic rocks may occur to the reader as an exception. But this exception is apparent only because the two cases differ radically in kind. In the case of hornblende the change takes place within the original crystal space and is not due to a chemical combination of hornblende and groundmass substances; while in the case of quartz the change takes place outside the crystal in the groundmass and is essentially in the nature of a chemical reaction between the quartz and some of the molecules of the groundmass.

As a further objection may be mentioned the fact that, while the alteration in general starts from surfaces in contact with the magma, yet in some cases it is seen to proceed along cracks which, as far as can be seen, are untouched by it. The first objection made is, however, so difficult of explanation that it is perhaps needless to bring up more.

And after all, when we come to examine the current theories we find them rather vague and unsatisfactory. It is easy to dismiss the subject with the explanation that resorption of the hornblende and subsequent recrystallization of its substance as augite and magnetite has taken place, but it is difficult to realize how such a process takes place in actual fact with the results that we see. It is hard to see why the original substance alone should

crystallize out of the magmatic solution and take on again its original outlines, or at least the crystallographic outlines of hornblende, with changed molecular and molar structure; while the magmatic solvent, much of which is also certainly capable of crystallization under the same conditions, abandons the hornblende and solidifies as groundmass crystals or basis.

On the "magmatic" hypothesis we should expect the frequent occurrence of glass basis or groundmass among the grains, an expectation in which we are universally disappointed. It is true that we find other minerals than the two principal ones among the alteration products, but their formation is easily understood on other grounds.

Conditions of alteration.—Let us now examine briefly the conditions under which the alteration does or does not take place; which may be broadly divided into two classes—chemical and physical.

The chemical conditions relate to the magma in which the crystals are formed and in which they float, and for reasons to be seen presently we shall confine ourselves in discussing them to the volcanic rocks.

On examining the whole range of volcanic rocks the most striking fact that we notice is that the alteration of hornblende and biotite is chiefly confined to the intermediate group—those with from 55 to 65 per cent. of silica—the trachytes, andesites, phonolites and tephrites (both leucitic and nephelinic). It is of comparatively rare occurrence in the two extreme groups, the acid and the basic rocks, though more frequent in the latter than in the former.

The alteration among intermediate rocks, especially the andesites, is so extremely common that it is the exception rather than the rule to find specimens which show no, or even very few, altered crystals. Among these rocks we expect beforehand to find a greater or less amount of alteration of the hornblende and biotite (excepting in a few structural types), and are seldom if ever disappointed in our expectations. Indeed in many regions[1] the

[1] OEBBEKE, Phillipines. Neu. Jahrb., B. Bd. I, 460; SIEMIRADZKI, Ecuador, ditto, B.

altered crystals predominate largely over the unaltered ones, occasionally to the total or almost total disappearance of the latter.

When we come to the acid and basic rocks we find that, while in both the alteration is comparatively rare, yet that there is a radical difference in the cause of the rarity in the two cases. In the basic magmas there are large amounts of iron oxides, magnesia and lime which here crystallize as pyroxene and olivine rather than as hornblende and biotite, which only rarely occur. When these two do occur, however, as in the hornblende basalts, they are almost invariably altered, so that the rarity of the alteration in these rocks is due to the rarity of the alterable minerals.

The case is quite otherwise in the acid rocks, where the bivalent metals, always in small quantities, go to form hornblende and biotite, pyroxene being of rare and abnormal occurrence in the rhyolites. Yet, notwithstanding their comparative frequency, though in small amounts, the alteration of these minerals is very unusual, the biotite being only occasionally blackened on the edges, while the hornblende is seldom changed.

We find in fact that while the absolute number of altered crystals is greatest in the andesites, yet that the proportion of altered crystals of hornblende or biotite among all those present is greatest in the basalts, where it reaches nearly 100 per cent., and decreases gradually, through the various intermediate rocks to the rhyolites where it is almost zero.

The general facts show that the chemical composition of the magma is a factor in the alteration process, though the rôle it plays is a rather obscure one. That it is a causal factor, *i. e.*, that the relative basicity of the magma in the intermediate and basic rocks immediately induces the alteration, does not seem to be probable in the light of facts to be given further on. It seems to be rather modifying in its action, the alteration which would

Bd., IV, 213, 1886; BLAAS, Persia, Min. Pet. Mitth., III, 474, 1880; HATCH, Arequipa, ditto, VII, 208–360, 1886; RUDOLPH, Peru and Bolivia, ditto, IX, 294, 304, 1887; K. VOGELSANG, Eifel, Zeit. d. d. g. G., XLII, 13, 18, 1890; GROSSER, Siebengebirge, Min. Pet. Mitth,, XIII, 77, 1892; G. H. WILLIAMS, Fernando Noronha, Am. J. Sci., XXXVII, 184, 1889.

otherwise go on being prevented by the acidity of the magma in the rhyolites and allied rocks.

Turning to the physical conditions involved we find the eruptive rocks divided into two great classes; the plutonic rocks being those which in general have solidified at a great depth and consequently slowly and under great pressure, while the volcanic rocks have solidified at, or near, the surface and hence more rapidly and under little pressure. We find on examination of eruptive rocks in general that the two classes show a marked difference in the condition of their hornblende and biotite crystals.

In the plutonic rocks the hornblende and biotite (which are among the oldest components) are almost invariably unaltered, the borders being as clear as the interior and not showing any opacity or granular augite opacite aggregate. It is evident from their fresh and clear appearance that since their formation no forces have come into play (atmospheric and dynamometamorphic action being left out of account), to change them from their original condition. This invariability of non-alteration in the plutonic rocks would be absolute (so far as my knowledge goes) were it not for two exceptions. Both of these are in nepheline syenite, one from Sierra di Monchique in Portugal,[1] and the other from Serra di Tinguá in Brazil.[2] These two rocks, it is well known, are connected with peculiar dike types, and the group in general presents peculiar features. These two exceptions cannot then invalidate the general law, deduced from very numerous and world-wide observations, that in the plutonic rocks the hornblende and biotite are unaltered.

This constancy of non-alteration is in striking contrast with the behavior of the two minerals in the volcanic rocks. In these the alteration is extremely common, quite the rule, in fact, among the intermediate and basic members, though comparatively rare in the latter, owing to rarity of hornblende and biotite, and only failing completely (or practically so) at the extreme acid end.

[1] V. WERVEKE, Neu. Jahrb., 1880, II, 151.

[2] GRAEFF, ditto, 1887, II, 236, 242, 244.

In fact, the more we study the igneous rocks, the more we are impressed with the great differences that the two minerals show in the two classes, as well as with the invariability of this behavior. In the one class of rocks we find the alteration "noticeable by its absence," while in the other the tendency is the other way, and its frequency is what most strikes us.

I have emphasized these respective characters because their invariability, resting as it does on such a broad basis of observations, shows that they are facts of prime importance for the solution of the problem. When we come to look at the class of volcanic rocks more closely, we find differences in special cases which are fully as constant and, while at first sight seemingly at variance with the above observations, are seen on further study not to clash but to be an almost equally important means to our end.

While the statement that the alteration is almost constant in the volcanic rocks (except the rhyolites, etc.) is true of the great majority of structural types, yet it has often been observed[1] that in the more glassy modifications the alteration is less than in the more crystalline; so that, speaking broadly, the frequency and amount of alteration may be said to be in roughly inverse ratio to the amount of glass basis present. Hence the above remarks on the invariability of alteration do not hold good for the highly vitreous forms, the obsidians, tachylytes, etc., in which both the hornblende and biotite are as a rule unchanged. Exceptions are to be found, but they are so few that they cannot impair our confidence in the general law that alteration is roughly inversely proportional to the amount of glass basis present, or, *coeteris paribus*, to the rate of cooling.

We must conclude, then, adopting the method of concomitant variations, and the factor of composition of the magma being eliminated by the researches of Hague and Iddings[2] and others (except in the rhyolites, etc.), that the alteration of hornblende and biotite does not take place under conditions of great

[1] *Cf* ZIRKEL, Lehrb., I. 723. ROSENBUSCH, Mikr. Phys., I. 484. II. (1887) 659.

[2] Bull. 17, U. S. G. S., 1885.

pressure and slow cooling, while conditions of slight pressure and slow cooling are extremely favorable, and again very rapid cooling and little pressure are unfavorable. The last set of conditions shows that the operation requires time, the crystals remaining unchanged because solidification, or else cooling below a temperature necessary for a molecular change, took place before alteration had time to set in. Our final conclusion, then, is that a diminution of pressure, together with a high temperature continued for some time, are the conditions necessary for the alteration.

Theory proposed.—This statement of conditions is based on such a large body of observations by the best petrographers on all classes of igneous rocks and from such a great variety of localities, and the exceptions to it are so few, that it seems to me we can safely accept it in trying to frame a theory to account for the alterations. Such a statement, by showing us the conditions under which the phenomena in question occur, points the way toward their explanation. The explanation of the alteration now proposed rests at bottom on the chemical nature of hornblende and biotite.

As has been briefly noted on page 257, and as may be seen on reference to any mineralogical handbook, these two minerals are much more complex in their molecular structure than pyroxene, one of the consequences of this complexity being, as is also indicated by experiment, that great pressure is necessary for their formation in an igneous magma,[1] with probably the presence of certain mineralizing agents.[2] That the latter are present in the magma is indicated by the content of hydrogen and fluorine in them in greater or less amounts.

This idea as to the conditions of formation of the two minerals, which Siemiradzki[3] was apparently the first to propose,

[1] The cases of uralitic hornblende and secondary biotite due to meteorological or dynamical agencies are not included in this statement. Only their formation in igneous magmas is referred to, and it is well known that a mineral may be formed in several quite different ways.

[2] *Cf.* LÉVY, Structures des Roches Eruptives. Paris, 1889, 90.

[3] SIEMIRADZKI, Neu. Jahrb. Bd. IV. 307, 1886.

does not carry with it the implication that augite as well may not be formed under the same conditions (as Siemiradzki seems to suppose). On the contrary, many facts, such as the inclusion of augite in phenocrystic hornblende and the like, show conclusively that augite can be formed under the same conditions as hornblende.

It would be perhaps rash to say that under plutonic conditions the bivalent molecules tend to form hornblende and biotite rather than pyroxene, but a hint that this is the case is furnished by the general preponderance of these two minerals over pyroxene in the plutonic rocks. The predominance is not, certainly, as great as might be wished to establish this point clearly, but that it exists is quite evident on considering the much greater abundance of the hornblende and biotite bearing plutonic rocks over the augitic; the granites, hornblende and biotite syenites and diorites surpassing, both in quantity and in number of occurrences, their augitic varieties as well as the gabbros in the broader sense. This question, however, which has no especial bearing on the present hypothesis, is merely brought in parenthetically.[1]

It is evident from their freedom from alteration in the plutonic rocks that hornblende and biotite are stable under plutonic conditions down to the last moment of solidification, while their constant alteration in the majority of volcanic rocks shows that they are unstable under diminished pressure, a fact that the experiments of Becker[2] and Doelter and Hussak[3] tend to confirm.

This instability[4] under conditions of high temperature and diminished pressure is due, according to my view, directly to

[1] It may be mentioned that Brögger (Gror. Ting. Serie, Krist. 1895, 36) states that in the grorudites the hornblende evidently represents an older phase of crystallization than the ægirine.

[2] BECKER, Neu. Jahr., 1883, II, 1 ff.

[3] DOELTER and HUSSAK, ditto, I, 1884, 23.

[4] ROSENBUSCH has already recognized this idea of instability, but without assigning a reason for it (Mikr. Phys., II, 660, 1887). *Cf.* G. H. WILLIAMS, Am. J. Sci., XXVIII, 259, 260, 1884.

the highly complex chemical character of hornblende and biotite. This is in accordance with the well-known chemical law that compounds are more unstable the greater their molecular weight and the more complex their molecular structure.

The theory here presented is that we must suppose the hornblende and biotite crystals to have been formed at an early (intratelluric) period under conditions of great pressure, and probably in the presence of mineralizing agents. As they are brought near the surface in the course of the eruption the pressure diminishes while the temperature remains high, till a point is reached where the substance is no longer stable. Here a molecular change is begun, inducing at the same time a molar change, so that the chemically and physically homogeneous mass of hornblende or biotite becomes a chemically and physically heterogeneous granular mass of augite and magnetite.

The formation of a mixture of diopside or augite and magnetite out of hornblende or biotite substance is easily conceivable and chemically quite possible, in the case of biotite lime being taken from the magma. Similar changes are not at all uncommon in the range of chemical mineralogy, and the resulting masses may be properly called paramorphs.[1] Perhaps the best analogous example is that of the change of leucite to so-called pseudo-leucite, a mixture of orthoclase and nepheline, as described by J. F. Williams.[2] In the case of hornblende, on this theory, the bulk analysis of the paramorph should be identical with that of the original mineral, or almost so (as is the case with pseudo-leucite). In the case of biotite which contains no lime (or, at least, only traces), that necessary for the formation of augite or diopside must be derived from the magma, while the potash of the biotite passes into this, or goes to form accessory feldspar. Such an interchange of atoms involves no theoretical difficulties, as similar ones are extremely common in cases of pseudomorphism and metamorphism. It may also be noted that the alteration of biotite produces larger

[1] Roth, Geologie, I, 64.

[2] Geol. Surv. Arkansas, 1890, II, 268.

magnetite grains and less augite than that of hornblende,[1] which is quite in accordance with its greater content of iron and lack of lime. No chemical difficulties are encountered in the case of the accessory alteration products, hypersthene, olivine and feldspar, the molecules necessary for their formation being present in the mother mineral.

The process requires apparently considerable time, and we may suppose that it continues from the point where instability begins till the mass becomes solid. It is possible that it may continue for some time after solidification has set in, but of this we have no evidence. Whether the magma is in motion or at rest has no effect on the alteration process, though the effects produced by a moving magma on the alteration product may have important consequences, as we shall see.

The formation of augite may take place at the same time as the hornblende, but is not hindered by diminution of pressure, and may possibly be favored by it. So that augite may and does crystallize out of the magma, either as small groundmass crystals or microlites, or as zonal accretions around phenocrysts brought up from below, at the same time that the alteration of hornblende and biotite is going on, or even after this has ceased for lack of alterable material.

The relative chemical complexity explains satisfactorily the fact that analogous alterations are seldom, if ever, seen in either the monoclinic or orthorhombic pyroxenes, or in olivine, which are much less liable to change, owing to their comparatively simple composition and structure. This also explains the recrystallization of melted hornblende as augite.

It will be evident that this theory of simple molecular change involves no change of form such as would necessarily arise on fusion or solution of the crystal. The preservation of the original shape is in accordance with the facts of pseudomorphism, and it is easily conceivable that the fine grained product should possess in many cases sufficient cohesion between its closely packed and interlocked grains to resist considerable dis-

[1] ZIRKEL, Lehrb., I, 721.

rupting force of a surrounding moving magma. In most cases, however, the mass will be somewhat incoherent, so that it will be broken up by the action of the current, yielding the rounded forms so generally observed, and leading to other consequences of importance.

It will also be seen that there is nothing in the theory incompatible with a true resorption or solution of the hornblende or biotite substance if it should be enveloped in a part of the magma in which it is soluble under the conditions prevailing. In this case, however, we would look for embayments and other true corrosion phenomena, with a disappearance of the dissolved substance, while the pseudomorphism process could go on at another, or the same, time.

It may seem, at first sight, that the starting of the alteration at the surface and its gradual progress inwards is a serious objection to this theory, in accordance with which we might think that the change should take place all at once through the whole crystal. But when we come to examine other cases of paramorphism such as the change of monoclinic to rhombic sulphur, or wrought to cast iron, we find that the changes here take place from certain definite points or surfaces (generally the latter), so that this uniform progress of alteration need not surprise us, especially in view of the fact that the alteration evidently requires time, as in all similar changes.

It is possible also that this method of progress is dependent on the hydrogen or fluorine content of the two minerals, the attraction between their molecules and those of the other constituents being lessened by diminished pressure at the temperature of the liquid magma, so that they tend to dissociate, thus causing a molecular disintegration and starting the molecular rearrangement. Such an action in their case would naturally start at the surface or along cracks, the walls of which need not be in actual contact with the magma. This action of the gaseous contents of the minerals would also explain the cases of non-alteration, in elsewhere altered crystals, where abutting against other phenocrysts.

The non-alteration in the very acid rocks is a fact which is difficult to explain by any of the hypotheses under consideration. Since the indications are that rhyolite when erupted is at a higher temperature than more basic rocks we could on the magmatic theories look for greater alteration in them than in the andesites or basalts. Since the reverse is the case their behavior militates rather against these theories. On the resorption theory proper we could also expect to find in the acid magmas a greater tendency towards solution of the ferromagnesian crystals, as is hinted at by Rosenbusch,[1] which we do not find. Glassy forms are extremely common in these rocks, and it is possible that the non-alteration is connected rather with this structural and physical peculiarity than with their chemical composition.

It is probably premature to discuss this question at present in view of the scantiness of our knowledge, so that we may merely assume that the large amount of SiO_2, and perhaps K_2O, exerts some deterrent effect on the process of alteration, of the nature of which we are ignorant. It is possible that the non-alteration in rhyolites is connected with the tendency of acid magmas to form hornblende and biotite rather than augite. It may also be suggested here that the influence of the composition of the magma on the alteration process may be analogous to the influence of the nature of a solvent on the molecular condition of the dissolved substance.[2]

CONSEQUENCES OF THE ALTERATION.

Action of the magma.—Accepting the alteration and its attendant phenomena as facts we may examine some of the consequences of this change and see what light they throw upon a few petrological questions.

The disrupting action of the moving magma current on the granular aggregate has already been referred to, yielding the rounded forms so commonly seen. This simple mechanical action of the current would tend to scatter the augite and

[1] ROSENBUSCH, Mikr. Phys., II., 660, 1887.

[2] NERNST, Theoretical Chemistry. London and New York, 1895, 387.

magnetite grains through the groundmass, and the process may often be seen, so to speak, in operation, where a tail or streamer of such grains is observed proceeding from a rounded, altered crystal.

It is not to be supposed that these grains will be resorbed or dissolved by the magma under ordinary conditions. The presence of augite microlites and crystals which have been formed down to the last stage before solidification, and the accretions about augite phenocrysts, precludes any such idea for the augite. Iddings [1] has shown that where resorptive action takes place the last minerals to crystallize should be the first to be resorbed, so that the magnetite grains are also safe from the attack of the magmatic ogre. It follows, therefore, that, provided the mass be in sufficient motion, the greater the alteration of hornblende and biotite the greater will be the abundance of augite and magnetite grains in the groundmass.

This conclusion may be supported by numerous observations:

H. Vogelsang[2] was the first to suggest that the "opacite" grains in the groundmass were derived from altered hornblende and biotite crystals by mechanical disintegration.

Zirkel[3] concludes that "many of the dark grains scattered through rocks are really the finely-distributed, powder-like particles of the pyrogenous alteration product of hornblende."

Mügge,[4] in his paper on the rocks of the Azores, makes the definite statement that augite grains as well may have been derived from altered hornblende and biotite crystals. We have also the interesting fact shown that the augites which crystallize out of the magma may be, and are in this case, of a different composition. On page 224 he says that certain groundmass olivines "appear in these cases, as sometimes in trachytes elsewhere, to have been produced from hornblende and biotite by resorption (Umschmelzung)."

[1] IDDINGS, Cryst. Ign. Rocks, Bull. Phil. Soc., Washington, XI., 105, 1892.

[2] H. VOGELSANG, Philosophie d. Geologie, Bonn, 1867, 192, *cf.* also his Die Krystalliten, Bonn, 1875, 157.

[3] ZIRKEL, Mikr. Pet. 40th Parallel, Washington, 1876, 95; also Lehrb., I., 717.

[4] MÜGGE, Neu. Jahrb., 1883, II., 1895.

Von Lasaulx[1] concludes that the rock-magma of the augite andesites of Hemmerich in the Siebengebirge must have been much more rich in hornblende at an early stage, and that the preponderance of augite, as well as magnetite, could have come about through resorption (Einschmelzung) of the hornblende. Grosser,[2] in a later work on the same region, comes to the same conclusion.

Hatch[3] notes a connection between the alteration of the hornblende and the presence of magnetite in the groundmass of certain Peruvian andesites, observing that in cases where the hornblende is "resorbed" magnetite is abundant, while in rocks where the mineral is unchanged the groundmass contains no magnetite grains. No definite mention of augite is made in this connection, but on page 359 he states that "hand in hand with the resorption of the hornblende goes an increase in pyroxene and magnetite."

Finally two examples drawn from my own experience may be given, one the hornblende basalts of Kula in Asia Minor,[4] and the other the andesites of Ægina and Methana.[5] In these the relation of the abundance of augite and magnetite grains in the groundmass to the alteration of the hornblende is well shown.

We see from these examples that in many andesites, as well as in other volcanic rocks, a part of the groundmass augites (and magnetites) have been derived from hornblende or biotite through alteration, whether "magmatic" or "molecular" it matters not.

It is possible that we have in this fact the explanation of the so frequent occurrence of imperfect grains of augite in the groundmass of many rocks. Augite and magnetite tend to be anomalous in this respect, as the groundmass crystals of the other rock-forming minerals—the feldspars, quartz, hornblende,

[1] Von Lasaulx, Sitz. ber. Niederrh. Ges. in Bonn., XLI., 155, 1884.

[2] Grosser, Min. Pet. Mitth., XIII., 77, 1892.

[3] Hatch, Min. Pet. Mitth., VII., 347, 1886.

[4] Am. J. Sci. LXVII, 121, 1894.

[5] Jour. of Geol., III, 21–46, 1895.

hypersthene, apatite and sphene — show comparatively few imperfect forms, and have a greater tendency toward definite crystallographic outlines. In augite, on the contrary, the groundmass crystals are often sharply divisible into imperfect grains and definite crystals.

Origin of some augite andesites.—By this idea of scattering of the granular alteration product of hornblende and biotite through the groundmass we are brought face to face with the question of the origin of many augite-andesites, and their classificatory separation from the hornblende and biotite-andesites. This problem has been touched upon by several writers and some discussion of it may be found in Zirkel's Lehrbuch (II, 817).

The separation of the augite from the hornblende-andesites has been opposed on the ground of the abundance of transition forms and the consequent difficulty of drawing a fast line between the two. Such an objection would however lie against almost any of the well established rock groups, and I fully concur with Rudolph[1] in his opinion of the importance of well characterized types at each end of the series.

That the two main classes may be rationally separated in general on the grounds of different mineralogical composition, together with correlated chemical and structural variation, cannot be doubted very seriously at the present time. But the alteration of hornblende and biotite tends to complicate matters somewhat

It must be stated here, and the fact must be insisted upon, that the hypersthene andesites in general, as Zirkel says, and many of the true augite-andesites are of an undoubtedly original character, *i. e.*, the component characteristic pyroxenes have crystallized normally out of the magma. On the other hand the facts of the alteration make it extremely probable that some of the augite-andesites are of a derivative character, *i. e.*, that their magmas were originally hornblendic or biotitic, but that these minerals have been replaced by augite and magnetite through the process of alteration and the consequences of the action of the moving magma on the products.

[1] RUDOLPH, Min. Pet. Mitth., IX, 316, 1887.

This idea was first broached by Von Lasaulx,[1] and his remarks are of such importance that a full quotation of the passage bearing on this point may be given:

"A conclusion which follows directly from the observations on the character of the constituents of the andesites of the Siebengebirge is this, that the less hornblende a rock holds the more it approaches a true augite-andesite, and the more the hornblende shows signs of resorption, so much the richer is the groundmass in finely divided magnetite. If . . . the hornblende is a constituent which has separated out of the fluid magma as one of the earliest at a great depth, then it would depend on how far the originally formed hornblende had undergone fusion and solution whether a rock appears in the upper regions as hornblende-rich or hornblende-poor. That augite is formed out of the magma easily and abundantly through resorption of enclosures and the earliest crystals can likewise be shown by experience; on the other hand hornblende appears to have been formed in this manner much less often. Likewise the magnetite of the groundmass can be increased by refusion of small hornblende crystals.

"An augite-andesite can therefore arise out of an original probably hornblende-andesite magma, if this remains in a state of liquidity so long that the hornblende which has been formed at a depth may be again wholly, or mostly, dissolved, and augite and magnetite be formed in its place."

The general similarity of the views expressed in the above quotation as to the origin of some augite-andesites with my own is apparent. It must be remarked, however, that the conclusions are as true of biotite as of hornblende, and also that I differ radically from Von Lasaulx in considering that the derivative augites are not crystallized out of the magma from dissolved hornblende substance, but are due to a molecular change and subsequent mechanical disintegration.

Zirkel expresses himself as against such an origin, saying that it would apply in any case not to the phenocrystic but only

[1] VON LASAULX, op. cit., 1858.

to the groundmass augites, and further that it is unscientific to connect closely a hornblende-free augite-andesite with a hornblende-andesite because part of the augite of the former could have been possibly in the condition of hornblende at an earlier magmatic period.

While not wishing to be in any degree polemical I must differ in this matter from Professor Zirkel, as it seems to me to be an inevitable conclusion from the facts that many of the groundmass augites in certain andesites have been so derived from altered hornblende substances. Mügge's example of the Azores trachytes already cited shows also that such derivative grains may attain the size of phenocrysts and hence be reckoned as such, through accretion of crystallizing augitic substances. Such a derivative origin must not, however, be attributed to all phenocrysts nor to the well formed augite-microlites and groundmass crystals. Nor is such an attribution necessary, as I have already pointed out that hand in hand with the alteration of hornblende may go on the crystallization of augite out of the magma. It may be mentioned here that Zirkel[1] speaking of the hornblendes in pyroxene-andesites says that they give the impression that they had nothing to do with those conditions of solidification in which the rock-mass as it exists at present was produced, from which the inference is to be drawn that they have been formed at a much earlier period.

But when Zirkel brings the charge of being unscientific against the idea of the derivation of augite-andesites from hornblendic magmas, he touches upon what seems to me to be a vital and important point in the question. If it were sweepingly asserted that all, or even the most, of the augite-andesites were to be connected with hornblendic magmas[2] his reproach would be justified, as being an unwarranted and too broad a generalization from the facts. But if it can be shown that certain augite-andesites are of independent origin while others are derivative from a previously hornblendic magma, then we have advanced a step

[1] ZIRKEL, Lehrb. II, 811.

[2] As VON LASAULX perhaps seems to do.

in our knowledge of this group of rocks—a step which may lead to the extension of our knowledge in other directions. The question as to whether the knowledge of such an origin should affect the present, classification is a question apart and need not be discussed here.

Acid augite-andesites.—A consideration of the phenomena already discussed, as well as others to be mentioned presently, has led me to the conclusion that, besides the normal augite-andesites which make up the greater part, such derivative augite-andesites do exist, in which a large part of the augite present is due to the alteration of hornblende. What the grounds are for this view I shall endeavor to show, though my remarks must be taken as suggestive of what may be the case, rather than as even approaching a full discussion of the subject.

It is quite well established that hornblende and biotite are the prevalent, or one might say favorite, ferro-magnesian silicates of the more acid rocks, though ægirine is abundant in acid phonolites and some trachytes, while augite is characteristic of the more basic rocks. This being so we could expect *a priori* to find the augite-andesites more basic than the hornblende or biotite-andesites. While this is the fact in many cases, yet exceptions are numerous, the abnormal acidity of many of the augite-andesites being remarked upon by Zirkel[1] and Rosenbusch,[2] as well as by others.

Some particular instances of the high acidity of augite-andesites occurring together with other andesites may be given. On the volcanic line in the Ægean Sea are found the two centers of Santorini, which has poured forth almost exclusively pyroxene-andesites, and Ægina-Methana, where hornblendic andesites and dacites are abundant as well as pyroxene andesites. I have elsewhere[3] pointed out the similarity in the general magmas of the two centers, and yet when we come to examine the rocks of the two districts in reference to the present point we meet with a

[1] ZIRKEL, Lehrb. II, 802.

[2] ROSENBUSCH, Mik. Phys. II, 651–683, 1887.

[3] JOUR. OF GEOL. III. 166, 1895.

somewhat striking result. In Ægina-Methana the analyses of the hornblende-andesite (excluding segregations) show an average silica percentage of 59.41, while at Santorini the pyroxene andesites are very acid, the silica average of the analyses quoted in the paper just cited, being 61.41 per cent., and the latest products of eruption range from 66.15 to 68.89.

Again we find in the Washoe District,[1] the Yellowstone Park,[2] Colombia,[3] and Ecuador[4] that eruption of the hornblende and pyroxene-andesites have taken place, and that many of the latter are as acid as, or more so than many, of the accompanying hornblende-andesites. Other instances of the abnormal acidity of augite-andesites that might be quoted are not rare, and the fregency of such occurrences is certainly surprising in view of what we might *à priori* expect.

In 1881 Gümbel[5] pointed out that the andesites of the Andes could be referred to two types, which he called the trachytic and the basaltic, the former with over, and the latter with under, 57 per cent. of silica. Later, in 1883, Cross[6] suggested that the augite-andesites may be divided into three groups; the "trachytic" with a high percentage of silica, the "basaltic" which are the most basic and pass into the true basalts, and the "intermediate" normal augite-andesites with a silica percentage of 56 to 60.

That the "intermediate" and "basaltic" augite-andesites have had the greater part at least of their augite crystallized out of the magma in a normal way, and hence that they are really augite-andesites in a true sense of the word, seems to be generally the fact; though cases might be brought up in which a derivative origin could be rightly attributed to a part of the augite even of these.

[1] HAGUE and IDDINGS, Bull U. S. G. S. No. 17, p. 33. *cf.* also CROSS, Laccolite Mt. Groups, XIV, Rep. U. S. G. S. 227, 1895.

[2] IDDINGS, Electr. Peak, XII Rep. U. S. G. S., 627, 628, 1892.

[3] Küch, Petr. vulk. Gest. Rep. Colombia, Berlin, 1892, 78, 79.

[4] Siemiradzki, op. cit., 205, 206.

[5] GÜMBEL, Sitz. ber., Münch. Akad., XI, 365 ff., 1881.

[6] Cross, Bull. No. 1, U. S. G. S., 36, 37, 1883.

Leaving these aside, we may confine our attention to the acid, "trachytic," augite-andesites. In the magma of such a rock we could naturally expect the formation of hornblende or biotite rather than augite.

Zirkel[1] explains the high acidity by the abundant presence of a glass basis which is often much more acid than the rock itself, as shown by Lagorio's[2] analyses. This explanation, however, only shifts the difficulty one step back, or rather states it in another form, since Lagorio's analyses also show that in basalts[3] the basis contains almost exactly as much silica as the rock.

The explanation which is suggested here is that these acid augite-andesites are derived from original hornblende or biotite-andesitic magmas. The magma came up with crystals of hornblende or biotite already formed, and these underwent alteration and disintegration as already described, while at the same time the rest of the ferro-magnesian molecules present in the magma crystallized as augite or hypersthene under the existing low pressure conditions.

Against this view may be brought a number of objections, one of those which most naturally occurs being that in the very acid rocks, as the rhyolites, the tendency is for the hornblende and biotite to remain unaltered. This objection is of weight, but it must be remembered that the acid andesites in question seldom, if ever, attain to the high acidity of the rhyolites, and further, that they are chemically quite different otherwise.

A detailed study of the various augitic andesites, and especially the more acid ones, would undoubtedly throw much light on the question and show which explanation (if either) was correct. Such a study would, however, carry us beyond the bounds of this article, and is, moreover, impracticable for me at present.

Variation with geological occurrence.—It is evident, from the facts of the alteration, that the physical conditions under which

[1] ZIRKEL, Lehrb. II, 819.

[2] LAGORIO, Min. Pet. Mitth., VIII, 458, 467, 1887.

[3] LAGORIO, op. cit., 479.

the magma is erupted and consolidated would, to a certain extent, control the formation of augite on this hypothesis. We may therefore examine a few cases of variation of mineralogical composition with geological occurrence which seem to bear out the view that many acid augite-andesites (and some of the more basic ones) are derived from hornblende-andesitic magmas of normal composition.

In the andesites of the Auvergne, as recently described by Fouqué,[1] the hornblende and biotite crystals are generally altered in the effusive lava streams, while in the very glassy effusives and in the dike rocks (which, according to Fouqué, have cooled quickly) they are fresh and augite is rare. It may be noted here, *en passant*, that in these rocks the presence of dusty inclusions in the apatite crystals seems to go hand in hand with the hornblende.[2]

In the augite-andesite flows of Mount Cimino, Deecke[3] observed that biotite predominates on the borders, while augite takes its place in the interior, of the streams.

The difference observed by Hazard[4] in the stock and sheet basalts of the Lausitz is noteworthy. The latter are normal olivine basalts, with or without nepheline, while the former are hornblende basalts. His conclusions are that hornblende separated out as phenocrysts only in the eruptive canal, that it was gradually resorbed, changing into augitic substance, and that further on, when the rock spread out as a sheet, or was injected into cracks, olivine invariably separated out. "It is hence possible to judge of the nature of the occurrence of our basalts (whether sheet or stock) from the constituents."

The explanation of such occurrences on the theory here suggested is quite simple. Hornblende and biotite, which have been formed at a depth, are preserved intact when the

[1] FOUQUÉ, L'Etude des Feldspaths, Paris, 1894, 193–270.

[2] *Cf.* BLAAS, Jung. Erupt. Gest. Persiens. Min. Pet. Mitth., III., 476 ff., 1880. Also, MERRILL, Erupt. Rocks fr. Montana. Proc. U. S. Nat. Mus., XVII., 642, 1895.

[3] DEECKE, Neu. Jahrb. B. Bd., VI., 231, 1889.

[4] HAZARD, Min. Pet. Mitth., XIV., 303 ff., 1894.

magma solidifies under sufficient pressure, as in the Lausitz stock; or where it cools so quickly that time is not given for alteration, as in the Auvergne dikes or the borders of the Mount Cimino streams. They undergo more or less alteration (and are hence replaced by augite) when such time is given them while they are simmering under slight pressure in the throat of the volcano, as seen in the lava flows of Auvergne and the Lausitz. In the case of the Mount Cimino flows we may suppose that the slow cooling of the interior under slight pressure gave opportunity for the replacement of the biotite by augite.

There are certain other cases where it seems possible that for some reason the magma was brought near the surface before the formation of hornblende or biotite had taken place to any extent, so that the crystallization of augite out of the magma took place, instead of either of the two other minerals.

As an illustration of this may be mentioned the volcanoes of Santorini. Here the highly acid pyroxene-andesites ejected by the later eruptions which formed the small island cones in the center of the bay show in the abundant glassy groundmass a large preponderance among the augites of well-formed prismatic microlites, as well as abundant hypersthene prisms, neither of which could be due to the alteration of hornblende, while augite grains are quite rare. The lava flows which go to make up the external crater ring of Thera and Therasia are in general much more crystalline and at the same time contain many more imperfect grains of augite, as I gather from examination of specimens collected by myself, and from some of Fouqué's remarks.[1] In this connection it is of interest to note that the hornblende crystals in the hornblende-andesites of Acrotiri very seldom show alteration phenomena.[2]

These explanations may seem forced or unnecessary to many, but they are only offered as suggestions of the applications of the idea of the instability of hornblende and biotite under eruptive conditions to certain problems of petrology. The forces

[1] Fouqué, Santorin, Paris, 1879, 291, *et al.*

[2] Fouqué, Santorin, 357.

involved in an eruption and the conditions under which the magma reaches the surface are probably so complex and certainly to so large an extent unknown to us that any explanation of such phenomena must be, after all, largely mere speculation at the present time.

Still it must be granted that the explanation of the above facts based on the process and consequences of alteration are within the bounds of reason, and our brief review points rather to than away from the conclusion that alteration of hornblende or biotite is responsible for a great part of the acid augite-andesites, as well as some of the more basic members of the group.

The foregoing remarks lead us directly to the consideration of another application of the ideas advanced in these pages to theoretical petrology, which may be briefly touched upon before closing this paper. I refer to the succession of erupted rocks at volcanic centers. In many places we find pyroxene-andesites among the later rocks following hornblende or biotite-andesites. Thus in the Eureka district the order of succession as given by Hague[1] is: hornblende-andesite, hornblende-biotite-andesite, dacite, rhyolite, pyroxene-andesite, and lastly basalt. Again at Sepulchre Mountain[2] the lower breccias are hornblende or biotite-andesites, while the upper and consequently later breccias are almost wholly of pyroxene-andesite. While recognizing the fact that the causes and circumstances involved are extremely various and complex, it may be suggested that such successions may be due in part to causes similar to those already spoken of in connection with the variation of mineralogical composition with geological occurrence; namely, that the hornblende or biotite of the original magma may have been replaced by augite during a period of liquidity under diminished pressure.

SUMMARY.

After a brief discussion of the current theories referring the alteration of hornblende and biotite to a resorptive action of the

[1] HAGUE, Geol. Eureka Distr., Mon. XX, U. S. G. S., 290, 1892.

[2] IDDINGS, op. cit., 634, 635.

magma and a statement of certain objections to them, the conditions under which the alteration does or does not take place are described and the conclusion arrived at "that a diminution of pressure together with a high temperature continued for some time are the conditions necessary for the alteration."

The theory is then proposed that the two minerals are stable in a molten magma only under plutonic conditions, and that the alteration is simply a molecular rearrangement induced by the diminished pressure in volcanic conditions.

The instability of hornblende and biotite as compared with pyroxene is due to their much more complex chemical constitution.

The influence of the chemical composition of the magma is described, but a discussion of it is held to be premature at present.

The disrupting action of the surrounding moving magma in the granular alteration product is touched upon, and it is pointed out that many of the groundmass augites and magnetites must have been derived from altered hornblende or biotite crystals.

It is also suggested that some of the augite-andesites, especially the more acid ones, may owe their augitic character to the alteration and subsequent disintegration of previously existing hornblendes or biotites, in accordance with the views of Von Lasaulx.

Finally, several applications of this idea to the explanation of certain rock occurrences and the succession of volcanic rocks are given.

HENRY S. WASHINGTON.

ON THE ORIGIN OF THE CHOUTEAU FAUNA.

IN a recent number of the JOURNAL OF GEOLOGY appeared an interesting paper discussing the Chouteau fauna of southern Missouri and its relations to the geographical conditions of the region in which it lived and to the other faunas living before it appeared.[1]

Although personally acquainted with the careful work done by the author on this and associated faunas, having gone over much of the ground discussed in this paper with him, still I am not quite prepared to accept the author's interpretation of his facts. And it is because his conclusions seem in some degree to be based upon principles which I have defended in papers already published, that I feel called upon to state in particular my reasons for dissenting from two of the opinions there expressed. The first of these opinions is expressed in Mr. Weller's proposition that the Chouteau fauna of Missouri, although not identical with it, was contemporaneous with the Chemung fauna of New York (p. 916). The second opinion is the conclusion, drawn from a comparative study of the genera and species of the fauna, that it arose from the mingling of two faunas, the one coming from the east, and represented in Devonian time by the Hamilton fauna of New York, and the other, the general Devonian fauna of Europe represented by the middle Devonian fauna of Iowa and British America.

The first of these conclusions seems to be consistent with, and but an extension of views advanced by me regarding the shifting of fauna.[2] But in order to speak of a fauna as moving from place to place and as occurring in one place above or below

[1] A Circum-insular Palæozic Fauna, by STUART WELLER, JOUR. GEOL., Vol. III., pp., 903–917.

[2] Proc. Amer. Assoc. Adv. Sci., Vol. XXXIV., pp. 222–234, 1886, and Amer. Geol., Vol. X., pp. 148–169, 1892.

the horizon it occupies in another, it is necessary to prove the identity of the moving fauna in its different localities; and, second, to have a continuous datum-horizon, either above or below, with which to measure its lower or higher position. Neither of these conditions are present in the case of the Chouteau fauna.

Furthermore, if the Chouteau fauna of Missouri were equivalent to the Chemung, its species must have descended from ancestors living before the Chemung period; but if it followed the Chemung, it must have been descended from a fauna living in Chemung time. The presence in the Chouteau of such species as *Productus hallana* (=*dissimilis*) and *Rhynchonella* (*Pugnax*) *acuminata* does not signify identity of age with the base of the New York Chemung, for two reasons. First, they belong to a part of the fauna which was directly continued up into the Carboniferous. It was this peculiarity which led to designating the fauna containing them as having a "Carboniferous aspect." The Hamilton fauna of New York lacked this Carboniferous aspect, while the middle Devonian faunas of Iowa and of Europe possess it, and it was this fact which suggested the interpretation of the Cuboides zone as evidence of the incursion of the new fauna from the west into the New York area.[1]

The second reason is that the presence of these species in the Chouteau does not indicate that the fauna is Devonian in the face of its many species of distinctly Carboniferous age, any more than their presence in the High Point fauna pointed to its Carboniferous age because *Rhynchonella acuminata* was a typical Carboniferous form. The fact that they are both contained in the typical Devonian beds of Iowa explains their presence both in the New York and Missouri rocks, but does not indicate identical age. The statement about "appearing as they do for the first time after the removal of the land barrier" furnishing good ground for this correlation, ceases to be forcible when we put the question, how do we know anything about the time the barrier was removed, except through the testimony of

[1] Bull. Geol. Soc. Amer., Vol. I., pp. 481–500, 1890; Amer. Jour. Sci. (3), Vol. XXV., pp., 97–104, 1883.

the fossils? Since the faunas are not the same it is necessary to assume some kind of barrier to separate them if they were contemporaneous.

But there seem to be very good reasons for continuing to believe that the two faunas are not contemporaneous, three of which are as follows:

1. The general facies of the fauna (generic as well as specific) is that of the typical Carboniferous faunas of both America and Europe, while the Chemung fauna is typically Devonian.

2. Several of the genera and species of the Chouteau fauna are not known in any Devonian rocks of America or Europe, but are present in other Carboniferous rocks of both America and Europe.

3. The other faunas which present closest relationship to that of the Chouteau are the Kinderhook, Marshall and Waverly, and wherever these faunas are known to succeed fossil-bearing rocks in continuous sections, they are above the Chemung faunas.

Until some evidence is at hand to show that one or other of these propositions does not represent the facts, it would seem to be necessary to regard the Chouteau as of more recent age than the Chemung of New York.

The second point, the dual origin of the Chouteau, seems to be a legitimate extension of the general principle assumed by me in explaining the cuboides[1] and succeeding faunas in New York state. It was with the expectation of finding this to be the fact that I gave the paper the same searching scrutiny which I found it necessary to give my own notes on the Cuboides fauna before I published them. As Mr. Weller states that he believes "the key to the whole problem (of the origin and evolution of the Mississippian fauna) is to be found in the dual origin of the faunas" as set forth in his paper (p. 915), the importance of making sure that there was a dual origin is apparent.

If, however, we have no evidence of any further duality of origin than that supposed to account for the Cuboides fauna in

[1] The Cuboides Zone and its Fauna, Bull. Geol. Soc. Amer., Vol. I., pp. 481–500.

the New York Chemung, it will promote the main investigation, in which I am as thoroughly interested as Mr. Weller can be, to have the fact clearly expressed at the outset.

The belief in the dual origin of the Chouteau fauna is drawn by Mr. Weller from an analysis of the fauna itself. I have examined the lists and the argument for new evidence bearing upon the general problem of the movement and modification of the fossil faunas concerned, but the evidence appears to me conclusive in proving a single and direct origin from the one general European type of Devonian represented already in the Devonian faunas of Iowa and other regions of the north and west.

Critical examination of the genera listed as belonging to the "East-American Devonian Province," but wanting in the "West-American and European Devonian Province" does not confirm the opinion of an origin for any of the genera directly from the former eastern province.

The genera so listed are *Aviculopecten*, *Cardiopsis*, *Edmondia*, *Pterinea*, *Sphenotus*, *Straparollus*, *Gennæocrinus*, *Platycrinus*, *Scaphiocrinus*, *Michelinia*.

Regarding them the following comments may be made:

Aviculopecten is reported in numerous species as European Devonian by Frech [1] and Tscherneyschew.[2]

Cardiopsis is a form of such uncertain generic affinities that the absence of the genus should not be concluded from the absence of the name in lists of foreign faunas. The close relationship of the one species, recognized by this generic name from America by Hall, to *Cardiomorpha*, *Megambonia*, *Dexiobia* and *Dualina* is sufficient to prevent it from furnishing any positive evidence of origin outside of the typical European Devonian.

[1] FRECH, Die Devonischen Aviculiden Deutschland, K. Preuss, Geol. Lands, Abhandl.

[2] TSCHERNEYSCHEW, Special Karte v Preuss, a Thüring, Staaten, Bd. IX. bft. 3, 1891.

Die Fauna des unteren Devon am Ostabhunge des Ural. Mem. du Comité Geol., Vol. IV., No. 3, 1893.

Edmondia De Koninck is a form of doubtful affinities and was described from Carboniferous specimens. Although it occurs in New York it is there a Chemung form, and on the theory that the Chouteau is later than the Chemung, there is no difficulty in supposing a common origin for its species. For if we apply the theory that these species came from the eastern Hamilton, we have the same reason for so accounting for the origin of the *Edmondias* of European Carboniferous, which is evidently absurd.

Pterinea Goldf. is a genus of wide range, from the Silurian to the Carboniferous, and its absence from a particular list of species in Devonian time cannot be taken as evidence that it was not then living under appropriate conditions in the same seas.

Sphenotus, until distinguished by Hall, in 1895, was recorded under the name *Sanguinolites* McCoy, or *Cypricardia* Lam., or *Cypricardinia* Hall. The genus under these names was known in the European Devonian, and one does not need to look to the eastern New York Devonian for its origin in the Chouteau.

Straparollus Montf. is reported under that name in Europe from the Silurian to the Triassic, and it is an ancient type and should not as a genus be used as indication of local origin of any fauna so late as the Carboniferous era.

All the other genera of Lamellibranchiata and Gastropoda, as well as all the Brachiopoda named in the list were known in the western or European Devonian fauna.

The crinoids mentioned, if not included in lists of European Devonian species may be there omitted because they did not appear until the Carboniferous time, in which case we have to account for their presence there as well as in America, or, as in the case of *Platycrinus* and *Scaphiocrinus*, they are only rarely found below the Carboniferous, and have to be accounted for as newly evolved genera rather than as descendants of species of the same genus in lower rocks.

The case of *Michelinia* must have been an oversight, for the genus is reported under that name from the Devonian of Europe,

and under the name *Pleurodictyum problematicum* Goldf. is a characteristic Devonian form of Europe as well as America.

Since all other genera in the list are known to have been present in the western Devonian fauna, there appears no positive evidence of a generic character to point to any double origin of the fauna.

Mr. Weller also cites a number of species as evidence of origin from two sources. Those traced to species in the western Devonian fauna require no comment; those for which an eastern origin is suggested are the following: *Athyris hannibalensis* Swallow, (*A. spiriferoides*); *Leptæna rhomboidalis; Orthis Michelini* (*O. vanuxemi*): *Eccyliomphalus paradoxus* (*E. laxus*); *Loxonema cf. hamiltonæ.*

Regarding the origin of these species, it may be said in general that the presence of closely allied forms in one Devonian fauna and nothing at all like them in a second great province, might be regarded as pointing to an origin from the first rather than the second source, but if there are species with equally close affinity in both provinces, then some other evidence must appear before we can say from which the later fauna has arisen.

Athyris hannibalensis may have found its ancestors among the common and very variable *A. concentrica* von Buch, of the European Devonian, as well as from the more specialized *A. spiriferoides* of the New York Hamilton.

Leptæna rhomboidalis is such a widespread, old and variable form that it would not be safe to say that it was wanting in any complete Devonian fauna.

Orthis michelini may have arisen from the *O. vanuxemi* of the Iowa Hamilton as well as from the same species in the eastern fauna.

Any species of genera of such wide range and variable character as either *Eccyliomphalus* or *Loxonema* cannot be safely cited as evidence without particular study and the discovery of some special distinguishing mark.

Eccyliomphalus Portlock is cited as a synonym under *Phanerotinus* Sow. by Zittel as having a range from Silurian to the Car

boniferous[1] and Hall[2] includes that genus as a synonym under *Euomphalus*, which is abundantly represented in the European Devonian fauna.

The genus *Loxonema* is as old as the Ordovician and the species are all so much alike in their general habit and variations that in order to trace the origin of any particular Carboniferous species, it would be necessary to show that it possessed some distinctive mark found in the species of some particular Devonian province and absent from the representatives of the genus of all other Devonian faunas. Thus we are led, by a critical review of both the genera and species, of which an origin from outside the Mississippi province of Devonian time is suspected, to the conviction that there is no positive evidence of such a course. On the other hand there seems to be no reason to doubt the natural succession of the Chouteau fauna from the Devonian fauna already in the province.

Although there seems to be little or no evidence that the Chouteau fauna was not all derived from one common source, it is not impossible that there may be traces of species which were not descended from any Devonian species of Europe. If the evidence brought forward in the paper on the Cuboides zone will bear the interpretation put upon it, there was such a mingling of two quite distinct faunas at the opening of the Chemung period in the New York area. There are no facts known to me to prevent the supposition that the Chouteau fauna may have species derived from the older fauna, but Mr. Weller does not mention any such facts, and I am not aware that there are any.

If it could be shown that the Chouteau fauna was of the same age as the base of the Chemung, it might be inferred that the mingling of faunas from different sources, which is supposed to have taken place in the New York region, affected also the faunas in the Ozark region of Missouri; but if the Chouteau is later than the Chemung, as I believe was the case, then the

[1] Handbuch der Palæontologie, II., p. 207.

[2] Palæontology, New York, Vol. V., Part II., Text, p. 54.

mixed fauna already occupied the eastern area when the Chouteau began, and from the evidence of the distribution of the Marshall and Waverly faunas, it is probable that it occupied the whole of the marine waters then lying over the interior of North America.

In conclusion I wish to emphasize a particularly valuable point made in the paper, viz., the connection between a new fauna and the sinking of the land. The theory of my Cuboides zone paper required some such hypothesis as this to account for the sudden incursion of the general western and northwestern Devonian fauna over the New York area. Mr. Weller has suggested a reasonable solution of the problem. But there is a still further inference to be drawn from this and similar facts. May not the occupation by the ocean of recently depressed land and the changed conditions of environment thus brought about, be a fertile and general cause in the modification of the faunas? From the facts already known, the inference seems quite probable that the initiation of new faunas, containing new genera, as well as new species, which is observed on tracing the succession of formations upwards in time, is intimately associated with the occupation by the seas and their contained organisms of recently depressed land surfaces.[1] Such radical modification of the conditions of environments as would thus take place furnishes a reasonable condition for the special activity in evolutional processes, which is indicated by the sharply distinct character of the faunas immediately following an unconformity such as is often noticed. The selective effects of migration from the midst of a general and adjusted fauna into new conditions of environment will undoubtedly account for some of the faunal changes which were taking place throughout geological time; but nowhere in a series of continuously forming strata is found such definiteness of grouping of the species of a fauna as after an unconformity, indicating depression of the land after a period of elevation and erosion.

HENRY SHALER WILLIAMS.

NEW HAVEN, CONN., March 2, 1896.

[1] See Ortmann's discussion of isolation as a factor in evolution. *Grundzüge der marinen Tiergeographie*, June 1896.

NORTH AMERICAN GRAPTOLITES.[1]

II. VERTICAL RANGE.

WITHOUT attempting to discuss at length the general aspects of this subject, attention may be directed to the following points:

1. The vertical range of the American species presents a complete parallel to the range in other countries. This parallel is not a general one only, but is exceedingly detailed, extending beyond the genera down to the species, which in each horizon correspond to those of the equivalent European horizon almost without exception, although of course not every European species occurs in America, or vice versa. Still the number of species common to the two sides of the Atlantic is surprising, and it will doubtless be increased by future research.

2. This detailed correspondence furnishes good ground for the expectation that eventually the American strata, like the European, will be mapped out, zone above zone, and for the hope that here, too, the graptolites may ultimately become one of the mainstays of stratigraphy. Much has of course yet to be done, but the peculiar associations of species in several collections so nearly parallel those which abroad characterize particular zones, that it is difficult to believe that here they have a different significance.

3. The extent of the range of the group as a whole, is unprecedented, as it extends from the Cambrian to and into the Carboniferous.

4. A striking peculiarity of the American fauna is the almost entire absence of the great European family of the *Monograptidæ*

[1] Continued from THE JOURNAL OF GEOLOGY, Vol. IV., No. 1, January-February, 1896, p. 102.

with its three genera and more than 100 good species. In America only one genus and two species are known, one of them from Arctic America. One reason for this absence is undoubtedly the predominance of limestone and the scarcity of shale in most of our Upper Silurian formations, but it cannot but be suspected that future collections may yield some of that wealth of forms to which European graptolithologists have long had access.

CAMBRIAN.

Genus and Species	Lower	Middle	Upper						
			St. John (N. B.) Group (Div. 3.)[2]			Canada[4]			
	Georgia Shales (Vermont)[1]	Acadia Group (St. John, N. B.)[2]	b	c	c′	Oldhamia zone (purple Farnham shales)[6]	Dictyonema-Olenidae zone	Dictyonema flabelliforme zone (Cape Rosier)	Upper Mississippi Valley[5]
Phyllograptus	?								
? cambrensis	W								
Bryograptus			—	—				—	
lentus				M[3]					
multiramosus								G	
patens			M	M[3]					
? retroflexus?			M[3]						
spinosus			M	M[3]					
sp.								L	
Clonograptus								L	
Dichograpsus				—					
proximatus				M[3]					
Staurograpsus								L	
Climacograptus	?								
? emmonsi	W								
Protograptus		—							
alatus		M							
Dendrograptus		?							—
hallianus									P
? primordialis		M							
Callograptus				—					
sp.				M[3]					
Dictyonema			—	—	—		—	—	
flabelliforme			M[3]	M[3]			L	L	
acadicum			M	M	M				
confertum (Lnrs *MS.*)?			M	M					
norvegicum ?				M	M				
Oldhamia (like O. radiata)						L			
Olenidae							L		

NOTES TO CAMBRIAN TABLE.

G signifies *fide* R. R. Gurley.

L signifies *fide* Charles Lapworth.[4]

M signifies *fide* G. F. Matthew.[2]

P signifies *fide* H. A. Prout.[5]

W signifies *fide* C. D. Walcott.[1]

[1] Walcott, Bull. 30, U. S. Geol. Surv., 1886, pp. 92–94.

[2] Matthew, List of Fossils found in the Cambrian rocks in or near Saint John, N. B., 1892, p. vi.

[3] Matthew, Trans. N. Y. Acad. Sci., 1895, pp. 262–273, Pls. XLVIII.–XLIX.

[4] Lapworth, Trans. Roy. Soc. Can. for 1886, V, sect. IV., p. 168.

[5] Prout, Amer. Journ. Sci., 1851, XI., p. 187.

[6] The shales are of Sillery age (*fide* Ells; see Walcott, Proc. U. S. Nat. Mus., 1894, XVII., p. 313) and should probably be placed at a higher level in (perhaps at the summit of) this table (*cf.* Walcott, Amer. Jour. Sci., 1890, XXXIX., pp. 112–114.)

ORDOVICIAN.

Genus and Species.	Lower.												Middle [12]					Upper [12]					
	Calciferous. [1]								Chazy [11]					Lower *Dicellograpsus* Zone.		Upper *Dicellograpsus* Zone.		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																	
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Phyllograptus			—		—		—	—															
angustifolius																							
anna					H L		G	G															
ilicifolius																							
" mancus (Lapworth var. *MS.* [6])			L G																				
loringi																							
typus							? G																
sp. indet.								G															
Schizograptus			—				?																
amii (Lapworth *MS.* [6])			L G																				
rarus (Lapworth *MS* [6])			L G																				
? sp.							G																
Goniograptus M'Coy																							
thureaui selwyni				A																			
Dichograpsus	—	—	—			—	—																
abnormis						G																	
flexilis	M		G																				
logani	M					G																	
milesi [7]																							
octobrachiatus			G																				
octonarius		H																					
ramulus			G																				
remotus			G																				
rigidus			G																				
sp.							G																
Tetragrapsus	—	—	—		—	—	—																
acanthonotus			G																				
alatus																							
approximatus			G																				
bigsbyi			G																				
crucifer																							

ORDOVICIAN—*Continued.*

Genus and Species	Lower: Calciferous[1]: Lower Zones: St. John Group (summit)[2]	Lower: Calciferous[1]: Lower Zones: Gros Maule[3]	Lower: Calciferous[1]: Lower Zones: Main Pt. Levis Zone[1]	Lower: Calciferous[1]: ? Intermediate: Miscellaneous[4]	Lower: Calciferous[1]: ? Intermediate: Phyllograptus anna Zone[5]	Lower: Calciferous[1]: Upper Zones: Pt. Levis[1]	Lower: Calciferous[1]: Upper Zones: Arkansas	Lower: Calciferous[1]: Upper Zones: Nevada[1]	Lower: Chazy[11]: Nevada	Lower: Chazy[11]: Mystic, Canada	Lower: Chazy[11]: Kicking Horse Pass	Lower: Chazy[11]: Dease River, B. C.	Middle[12]: Trenton Limestone	Middle[12]: Lower *Dicellograpsus* Zone: New York and Canada	Middle[12]: Lower *Dicellograpsus* Zone: Arkansas[13]	Middle[12]: Upper *Dicellograpsus* Zone: Cove Fields, etc.[14]	Middle[12]: Upper *Dicellograpsus* Zone: Magog, Canada	Upper[12]: Utica Horizon: Mohawk Valley	Upper[12]: Utica Horizon: Lake St. John	Upper[12]: Utica Horizon: Lower Cincinnati	Upper[12]: Utica Horizon: Lower Maquoketa	Upper[12]: Lorraine Horizon: Upper Maquoketa	Upper[12]: Lorraine Horizon: Lorraine Shales (New York)
Tetragrapsus—*cont'd.*																							
denticulatus	....	....	G																				
fruticosus	....	....	G	....	H L																		
headi																							
hicksi	....	....	...	A																			
quadribrachiatus	M	....	G																				
serra	....	H	G	....	H	G	G																
sp.?	M																						
Holograptus			?		?																		
? richardsoni	....	....	G	....	H																		
Didymograpsus	—	—	—		—	—	—	—	—	—	—	—		—	—			? [30]					
arcuatus																							
bifidus	....	....	....	....	H	G	....	....	G [11]														
bipunctatus																							
caduceus	....	....	....	....	....	....	? G																
convexus	....	....	....	....	....	....	....	....	....	....	....	....	....	G [18]									
? elegans	....	....	....	....	....	....	....	....	....	....	....	....	....										
sp. nov. near euodus	....	....	....	....	L	....	....	....	....	....	L												
extensus																							
extenuatus																							
hirundo (=constrictus)	....	H	G																				
indentus	M	....	G																				
murchisoni furcillatus	....	....	....	A																			
nitidus	M																						
patulus	M	....	L G																				
pennatulus																							
perflexus	....	....	....	....	....	....	....	G															
? rectus	....	....	....	....	....	....	....	....	....	....	....	....	....	[18]									
sagitticaulis	....	....	....	....	....	....	....	....	....	....	....	L	....	×	G								
serratulus	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G	....	....	Wh [30]					
similis	....	....	....	....	H																		

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle [12]					Upper [12]					
	Calciferous [1]								Chazy [11]					Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																	
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Didymograpsus—*cont'd.*																							
cf. superstes	....	....	....	....	....	....	....	....	....	....	....	....	....	L									
spp. nov.	....	....	....	....	....	....	? G	....	....	....	....	....	....	L									
sp. ("nar. thread like")	M																						
sp.? ("very nar.")	M																						
Clematograptus																							
multifasciatus	....	....	....	....	....	....	....	....	....	....	....	....	....	H L									
Nemagrapsus																							
capilaris [8]	....	....	....	....	....	....	....	....	....	....	....	....	....	LG [15]									
Stephanograptus																							
crassicaulis	....	....	....	....	....	....	....	....	....	....	....	....	....	G									
exilis	....	....	....	....	....	....	....	....	....	....	....	....	....	L G									
gracilis	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G								
surcularis	....	....	....	....	....	....	....	....	....	....	....	....	....	× G									
New form allied to Stephanograptus	....	....	....	....	....	....	....	....	....	....	....	L											
Amphigraptus																							
divergens	....	....	....	....	....	....	....	....	....	....	....	....	....	G									
Stenograptus (Lapworth *MS.*[6])																							
speciosus (Lapworth *MS.*[6])	....	....	L G																				
Leptograptus																				?			
annectans	....	....	....	....	....	....	....	....	....	....	....	....	....	....	? G	....	....	W G	....	? G			
flaccidus	....	....	....	....	....	....	....	....	....	....	....	....	....	....	. . .	....	....	....	H				
subtenuis	....	....	....	....	....	....	....	....	....	....	....	....	....	× G									
? macrotheca	....	....	G																				
Azygograptus														?									
? walcotti	....	....	....	....	....	....	....	....	....	....	....	....	....	L G									
Dicellograpsus																L							
anceps	....	....	....	....	....	....	....	....	....	....	....	....	....	A									
divaricatus	....	....	....	....	....	....	....	....	....	....	....	....	....	×	G								
elegans	....	....	....	....	....	....	....	....	....	....	....	....	....	....	? G								
forchhammeri	....	....	....	....	....	....	....	....	....	....	....	....	....	A [16]									

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle [12]					Upper [12]					
	Calciferous [1]								Chazy [11]					Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																	
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic. Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog. Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Dicellograpsus—*cont'd.*																							
gurleyi [17]														L G									
intortus														L	G								
" polythecatus														G									
rigidus															G								
sextans														×				? [30]					
" tenuibrachiatus (*nom. nud.*)														L									
Dicranograptus														—	—	—	—	—		—			
cf. clingani														A [18]									
dissimilaris																							
furcatus														× [18]									
? inequalis																							
nicholsoni														? A				G L					
" arkansasensis															G		G						
" whitianus [19]																							
" parvangulus															G								
" diapason														G									
ramosus														×	G		G	WhG		?G			
" rectus														L									
" spinosus (*nom. nud.*)														L		L							
" tardiusculus (*nom. nud.*)														L		? L							
Climacograptus								—			—	—		—	—	—	—	—		—			
antiquus												?L		L	G								
bicornis														×	G	L	G	WhG					
caelatus [9]								L G			L												
caudatus																	G						
" laticaulis																	G						
cf. confertus																A							
kamptotheca																	G						
oligotheca																	G						
phyllophorus [21]														G									

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle [12]					Upper [12]					
	Calciferous [1]								Chazy [11]					Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																	
	St. John Group (summit) [2]	Gros Maule [3]	Main Pt. Levis Zone [1]	Miscellaneous [4]	Phyllograptus anna Zone [5]	Pt. Levis [1]	Arkansas	Nevada [1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas [13]	Cove Fields, etc. [14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Climacograptus—*cont'd.*																							
scalaris [9]																							
scharenbergi														L G		L	G						
typicalis																		G		U G			
wilsoni																	G						
Diplograpsis						—	—	—			—	—	—	—	—	—	—	—	—		—		—
angustifolius											L			×	G								
dentatus						G	G											29					
euglyphus												L		LG		? L							
foliaceus											L			×	G	L	G	Wh G					? G
" *mut.* amplexicaule										G			HG										
" basilicus (*nom. nud.*)																L							
" confertus (*nom. nud.*)																L							
" *mut.* laciniatus														18									
" platydens (*nom. nud.*)																L							
foliosus														18									
"folium His. (as of Nicholson)" [10]																							
hudsonicus [20]																							
inutilis						G																	
latior (*nom. nud.*)																							A
peosta [22]																					G		
" *mut.* perexcavatus														LA			? G						
putillus [22]																					G		
quadrimucronatus																			H				
ruedemanni Gurley, sp. nov.																		G					
stenosus																		G					
trifidus [23]															G								
truncatus																? L	? G						
whitfieldi														G	G								
sp.								G															

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle[12]					Upper[12]					
	Calciferous[1]								Chazy[11]					Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																	
	St. John Group (summit)[2]	Gros Maule[3]	Main Pt. Levis Zone[1]	Miscellaneous[4]	Phyllograptus anna Zone[5]	Pt. Levis[1]	Arkansas	Nevada[1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas[13]	Cove Fields, etc.[14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Cryptograptus							—	—			—	—		—	—	—	—						
antennarius							G																
tricornis							G	G		G	L	L		×	G	L	G						
Lasiograptus														—	—		—						
bimucronatus														L									
mucronatus														×	G		G						
Glossograpsus								—		—	—			—	—								
arthracanthus														18									
ciliatus								L G			L	L		G I	G								
setaceus														18									
spinulosus											L			H	G								
Reteograptus	—													—					—				
eucharis																			H				
geinitzianus														× G									
tentaculatus	? M																						
Trigonograpsus			?			—	—																
ensiformis			? G			G	G																
Clathrograptus														—									
cuneiformis														L									
Dendrograptus							—								—		—	—		—			
arundinaceus[24]																		H G					
compactus																		W G					
diffusus																							
divergens																							
erectus																							
flexuosus																							
fruticosus																							
gracillimus																				Lq			
gracilis																							
cf. serpens							G																
simplex																		W G					

ORDOVICIAN—*Continued.*

Genus and Species	Lower												Middle[12]					Upper[12]					
	Calciferous[1]								Chazy[11]					Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																	
	St. John Group (summit)[2]	Gros Maule[3]	Main Pt. Levis Zone[1]	Miscellaneous[4]	Phyllograptus anna Zone[5]	Pt. Levis[1]	Arkansas	Nevada[1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas[13]	Cove Fields, etc.[14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Dendrograptus—*cont'd.*																							
striatus																							
tenuiramosus	....	....	....	....	....	....	....	....	....	....	..	....	....	....	....	....	....	W G					
unilateralis	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G						
spp. indet. 3 (fragments)	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1 G	....	2 G						
Callograptus		—	—																				
elegans	....	H	G																				
salteri	....	H	G																				
Dictyonema	—			—		—							—	—	—		—						
grande																							
cf. homfrayi	....	....	....	A																			
irregulare	....	....	....	....	....	G																	
murrayi																							
neenah	....	....	....	....	....	....	....	....	....	....	....	....	25										
obovatum	....	....	....	....	....	....	....	....	....	....	....	....	....	....	G								
perexile	M																						
quadrangulare	M																						
robustum																							
spp. incert.	....	....	....	....	....	....	....	....	....	....	....	....	....	G	....	....	G						
Desmograptus			—																				
macrodictyon	....	....	G																				
Ptilograptus			—																				
geinitzianus	....	....	G																				
plumosus	....	....	G																				
Thamnograptus								—						—	—		—						
anna	....	....	....	....	....	....	....	G															
barrandi	....	....	....	....	....	....	....	....	....	....	....	....	....	× G	G	...	G						
capillaris	....	....	....	....	....	....	....	....	....	....	....	....	....	H									
typus	....	....	....	....	....	....	....	....	....	....	....	....	....	H G									
Inocaulis																				—			
arbuscula	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	U			

ORDOVICIAN—*Continued.*

Genus and Species	Lower													Middle[12]					Upper[12]				
	Calciferous[1]								Chazy[11]					Lower *Dicellograpsus* Zone		Upper *Dicellograpsus* Zone		Utica Horizon				Lorraine Horizon	
	Lower Zones			? Intermediate		Upper Zones																	
	St. John Group (summit)[2]	Gros Maule[3]	Main Pt. Levis Zone[1]	Miscellaneous[4]	Phyllograptus anna Zone[5]	Pt. Levis[1]	Arkansas	Nevada[1]	Nevada	Mystic, Canada	Kicking Horse Pass	Dease River, B. C.	Trenton Limestone	New York and Canada	Arkansas[13]	Cove Fields, etc.[14]	Magog, Canada	Mohawk Valley	Lake St. John	Lower Cincinnati	Lower Maquoketa	Upper Maquoketa	Lorraine Shales (New York)
Buthograptus[26]													—										
laxus													H										
Protovirgularia														—									
dichotoma														? G									
Corynoides														—		—	—						
calicularis														A		L	G						
Dawsonia			—											—		—				—			
acuminata																							
campanulata														A		A							
monodon			G																				
rotunda																							
tenuistriata																							
tridens			G																				
spp. 3 or 4 (Ulrich *MS*)																				U G[27]			
sp.														A									
Caryocaris			—				—	—															
curvilatus			G					G															
oblongus			G																				
wrightii							G	L G															
Megalograptus																				—			
welchi[28]																				Mi			
Phycograptus														—									
brachymera														G									
macromera														G									
laevis														G									

NOTES TO ORDOVICIAN TABLE.

× signifies range admitted by all observers.
A signifies *fide* H. M. Ami.
G signifies *fide* R. R. Gurley.
H signifies *fide* James Hall.
L signifies *fide* Charles Lapworth.
M signifies *fide* G. F. Matthew.
Mi signifies *fide* S. A. Miller.
U signifies *fide* E. O. Ulrich.
W signifies *fide* C. D. Walcott.
Wh signifies *fide* R. P. Whitfield.

[1] *Calciferous*—The table given here is the result of a study of a considerable quantity of material from four American localities, as follows:

(*a*) The Point Levis shales. Two collections were examined. The first—from the main zone—was a very large one, containing a number of characteristic species, among which *Dichograpsus flexilis* and *Phyllograptus ilicifolius var.* were conspicuous. They occur in black shale.

(*b*) The second and smaller collection from the Point Levis shales was from a hard ringing iron-gray shale, lithologically quite different from the much softer, black shale of the first collection; locality, 1⅛ miles north of the East Railway Station, Levis, Canada. As will be seen from the table, the fauna was strikingly different from that found in the softer, black shale. It was remarkable not so much for the species present (though the *Diplograpsidæ* seem highly characteristic), *as for those absent*. Indeed, it is hardly possible to examine a fragment of the black shale without finding a number of species which appear never to occur in the hard gray shale.

Analogy with British stratigraphy suggests that the difference is one of horizon and this view is reinforced by an examination of collections from the Calciferous beds in Nevada and Arkansas, the fauna of which agrees in a general way with that of the hard, gray Point Levis shale, and differs widely from that found in the black shale in the same locality. Further, as in Europe, so in Nevada, *Didymograpsus bifidus* marks a distinctly higher horizon.

Perhaps intermediate faunas (implying intermediate horizons) may exist. Some of those given by Ami appear to indicate that such is the case (see below), but I think the main divisions will not thereby be obscured. The species whose horizons are indicated in the table are those which I have myself identified. The exact ranges of the others are unknown, being merely Calciferous generally.

(*c*) A large collection from the Piñon Range, at the crossing of the Eureka and Palisade Railroad, at Summit, Nevada; collector, C. D. Walcott. This collection shows some very interesting and unique features, notably, the presence of *Phyllograptus* entirely unaccompanied by any traces of *Tetragrapsus* or more highly compound dichograptid genera, the presence of *Climacograptus* and *Glossograpsus*, and the extreme profusion of individuals of *Caryocaris* which amount to more than half the entire number of specimens.

(*d*) A rather small collection from Arkansas, in which, however, a number of Calciferous species could be made out.

From a general survey of the above collections, we may, I think, suspect that several species imply a higher horizon than the main (*Dichograpsus flexilis*) zone. I should at present name here (questioningly): *Phyllograptus anna*, the *Diplograpsidæ* generally, *Glossograpsus*, *Dictyonema irregulare*, *Thamnograptus anna*.

That this classification by no means exhausts the zone problem of our Calciferous, may be inferred from the fact that other collections imply in the peculiar association of species exhibited at least two other horizons. On them I am not, however, at present prepared to report in detail, and will only say that in one *Phyllograptus typus* (which seems to be absent from the main zone, the genus being there represented by great numbers of *P. ilicifolius mancus*, Lapw. *MS.*), is the dominant species, and that the other is characterized mainly, if not almost entirely by several *Dictyonema* species which are absent from the main Point Levis zone. This last feature (that the zones are for the most part *mutually complementary*) is a striking and important one.

Finally, I may say that the table here given, classifies every species, I believe, ever recorded, except certain faunas reported by Mr. Ami (in Ells, Ann. Rep. Geol. Surv. Can. for 1887 (1889), Pt. K). The twelve Calciferous faunas reported were not classified into zones. Careful study of them leads me to think that they harmonize fairly well with the division here suggested, viz., into a lower zone rich in (especially dichograptid) species, and an upper zone with a much less rich fauna in which the diplograptid element is conspicuous.

Newly introduced species whose horizon is not clearly defined are listed in the miscellaneous column.

[2] Stage *d* of Division 3 of Matthew (reference, Note 2, Cambrian table).

[3] Tabulated from Hall (Canad. Org. Rem., Dec. II., 1865, pp. 68–142).

[4] See last paragraph of Note 1.

[5] Tabulated from Hall (*loc. cit.*, in Note 3, above), and from Lapworth (Trans. Roy. Soc. Can., 1886, V., Sect. IV., p. 184).

[6] Identification by Lapworth from specimens sent (in *MS.* report to author).

[7] From a loose bowlder.

[8] This species *fide* Ami (Bull. Geol. Soc. Amer., 1891, II, table p. 495), occurs in the Calciferous. On p. 492 (the only list in the paper which contains this species), to the specific diagnosis is added a " ? " In this connection I may say that I identified a specimen in the Nevada collection (the same horizon) as *capilaris* Emmons, but later, after obtaining Emmons' species at Stockport, found the Nevada specimen to be *Thamnograptus anna* Hall.

[9] The form found by Mr. Ami (Ann. Rep. Can. Surv. for 1887 (1889), p. 50K) in the (upper) Calciferous, and referred by him to *Climacograptus scalaris* Hisinger, is in all probability, this species. It could not be *C. scalaris*, inasmuch as that species is nowhere else found below the very summit of the Ordovician (Brachiopod schists of Sweden; and, as var. *normalis* Lapw., at base of Upper Silurian in Britain). See also note 21.

[10] This species, listed by Ami (in Ells, *loc. cit.*, p. 50K), can hardly be *Cephalograpsus folium* His., as that species is known only in the highest beds of the Ordo-

vician (Upper Graptolite schists of Sweden). In the Upper Calciferous shales of Nevada, many specimens of *Phyllograptus* occur, some of which, not being well enough preserved to show all the *Phyllograptus* structure, present a deceptive *folium* aspect. Whether this is the explanation of Ami's *folium* or not I cannot say, as I have not seen the specimens.

[11] *Chazy.*—Little is known in regard to the graptolite fauna of this horizon. In Nevada, *Didymograpsus bifidus* Hall, occurs in strata certainly supra-Calciferous and probably Chazy horizon (*fide* oral statement of C. D. Walcott.)

In a small collection from the Chazy at Mystic, Canada, a few poorly preserved (mostly fragmentary) graptolites were seen. Only *Diplograpsis foliaceus* Murch. (*mut. amplexicaule* Hall), and *Cryptograptus tricornis* Carr., could be determined with any certainty. Some *Didymograpsus* fragments of two species completed the collection.

Further, somewhere between the *Dichograpsus* fauna characteristic of the Calciferous, and the *Dicellograpsus* faunas, characteristic of the (certainly pre-Utican and probably) Trenton, are to be placed the faunas occurring in the beds at Kicking Horse (Wapta) Pass, Rocky Mountains (Lapworth, 1886, Ann. Rep. Geol. Surv. Can., II., pp. 22D–24D; also Science, 1887, IX., p. 320), and those along Dease River, British Columbia (Lapworth, 1889, Ann. Rep. Geol. Surv. Can., III., pp. 94B, 95B; also Can. Rec. Sci., III., pp. 141, 142). Approximately at least, these beds are of the same age, and in a general way, and as a diagnosis by exclusion, may be said to be Chazy.

[12] *Trenton-Lorraine.*—Besides faunas already recorded, the following collections have been studied:

Lower *Dicellograpsus* zone; Lower Falls, Kinderhook Creek, near Stockport, N. Y. About three tons of excellent material collected by the author. Also a rather small collection from Schodack Landing, N. Y.

Upper *Dicellograpsus* zone: Large collection from Magog, Canada.

Graptolite Zones.—As remarked by Lapworth (Trans. Roy. Soc. Can for 1886, V., Sec. IV., p. 176), the Trenton limestone should, in all probability be regarded as a deep-water deposit. Its age not improbably embraces both the Lower and Upper *Dicellograpsus* zones. Briefly the evidence is:

(*a*) At Schodack Landing, Rensselaer county, N. Y., Ford (Amer. Jour. Sci., 1884, XXVIII., p. 206) found the Lower *Dicellograpsus* fauna associated with a brachiopod fauna which, as regards age, may be anywhere from Trenton to Lorraine, but cannot be pre-Trenton.

(*b*) In spite of assertions to the contrary, the graptolite faunas of the *Dicellograpsus* zones are not only identical with, but are strongly contrasted to those of the Utica shale proper (that of the Mohawk Valley). And Lapworth's statement that, with the asserted exception of five species, not a shadow of palæontological evidence has yet been adduced to show that these Norman's Kill or Marsouin rocks are newer than the Trenton," is fully justified (*loc. cit.*, p. 171).

(*c*) Parallelism with European (principally British) stratigraphy, strongly confirms the order of superposition suggested by the faunas, viz., in ascending order:

$$\left.\begin{array}{l}\text{Lower Dicellograpsus zone}\\ \text{Upper Dicellograpsus zone}\end{array}\right\} = \text{Trenton (?)}$$

Utica.

If now the *Dicellograpsus* zones cannot be pre-Trenton, and must be sub-Utican, by exclusion they only can only be Trenton, and as a rough approximation we may say lower and middle Trenton respectively. Following them, of course, are the Utica and Lorraine horizons.

[13] Contrary to the opinion formerly expressed as the result of insufficient study, the Arkansas beds belong rather to the Lower than to the Upper *Dicellograpsus* zone. To show this, the following table is given showing the range of the species as ascertained in New York and Canada:

Arkansas Species	Lower Dicellograpsus Zone	Upper Dicellograpsus Zone	Utica	Supra Utican
Didymograpsus sagitticaulis				
" serratulus				
Stephanograptus gracilis				
Leptograptus (like annectans)				
Dicellograpsus rigidus	Gl			
" divaricatus	×			
" intortus	×			
" elegans	Var.	LH	UH	
Dicranograptus ramosus	×	×	×	
" nicholsoni			×	
" " parvangulus				
" " arkansasensis		×		
Climacograptus antiquus ?	×	Var.		
" bicornis	×	×	×	
Diplograpsis foliaceus	×	×		
" trifidus				
" whitfieldi				
" angustifolius	×			
Cryptograptus tricornis	×	×		
Lasiograptus mucronatus	×	×		
Glossograpsus ciliatus	×			
Dictyonema obovatum				
Dendrograptus sp				
Thamnograptus barrandi	×	×		

The following abbreviations mean: Gl. Glenkiln; LH. Lower Hartfell; UH. Upper Hartfell. The species so marked are known in America only in Arkansas, and the comparison is with their ascertained foreign range in strata equivalent to those represented in the column.

[14] Zone first noted by Lapworth (Trans. Roy. Soc. Can. for 1886, V., Sec. IV., p. 172), as "Zone without *Coenograptus gracilis.*" The collections referred here were from the Cove Fields, from St. John Market, Quebec, and from the north side of the Island of Orleans. Subsequently Ami (Ann. Rep. Geol. Surv. Can. for 1887, p. 46K), found *Stephanograptus* ("*Coenograptus;*" species not stated) in this zone.

[15] In the black shales of the Lower *Dicellograpsus* zone in the Hudson Valley, I have found typical specimens of this species. I believe it does not occur at other horizons. Ami (Ann. Rep. Geol. Surv. Can. for 1887, p. 53K; consult also 51K, where the same zone appears to be represented), reports it, however, from a horizon certainly Calciferous, and apparently Upper Calciferous. (See also Note 8.)

[16] It is doubtful whether this is Geinitz's species. More probably it is referable to the next, as there appears to be but one species closely allied to Geinitz's at this horizon, and that one Prof. Lapworth (*MS.* report to author) says is distinct. *Cf.* next.

[17] Probably Ami's *D. forchhammeri* is this species. *Cf.* preceding note.

[18] As suggested by Lapworth (Geol. Distrib. Rhabdophora, p. 31), the following species described by Emmons (*American Geology*, 1856. Pt. 2, pp. 104–111), are probably referable to this zone.

Didymograpsus ? ("Monograpsus") elegans Emm.
" ? ("Monograpsus") rectus Emm.
Dicranograptus ? ("Cladograpsus") inequalis Emm.
" ("Cladograpsus") dissimilaris Emm.
Diplograpsis foliaceus Murch.
(as D. dissimilaris Emm.)
(as D. rugosus Emm.)
(as D. obliquis Emm.)
(as D. laciniatus Emm.)
foliosus Emm.
Glossograpsus arthracanthus.
" setaceus Emm.

Further, Didymograpsus ? ("Monograpsus") rectus Emm., from "Columbia county (N. Y.), in the Taconic Shales," probably belongs at this horizon, which is very well developed in Columbia county. The species presents every appearance of an accidental juxtaposition of two fragments.

[19] As an appendix to the table, the following fauna reported by Dr. C. A. White, (Rep. Wheeler Surv, 1875, IV., pp. 62–66), from strata five miles north of Belmont, Nevada, may be noted. The identifications have been made after a study of the types in the National Museum. As far as the stratigraphic value of the species is concerned, the horizon might be anywhere from the Lower Dicellograpsus zone to the Utica, both inclusive.

White's Name	Identification
Graptolithus (Climacograptus) ramulus.	Dicranograptus nicholsoni whitianus.
Graptolithus (Diplograptus) pristis Hall ?	Diplograpsis foliaceus.
Graptolithus (Diplograptus) hypniformis.	Diplograpsis foliaceus ?
Graptolithus (Diplograptus) quadrimucronatus.	Diplograpsis sp.?

[20] From a loose slab carried from its original site by commerce; age, "the Hudson River Group."

[21] The "*Climacograptus scalaris*, Hisinger, var. *normalis*, Lapworth," of Ami (Ann. Rep. Geol. Sur. Can. for 1887 (1889), p. 78K; Bull. Geol. Soc. Amer., 1891, II., p. 496), is almost certainly this species, as this is the only one at this horizon to which it could refer. Hall's *scalaris* of 1847 consists of four species. *Cf.* Note 9.

[22] "Hudson River Group of Iowa" (Hall).

[23] Cf. *D. foliaceus calcaratus*, Lapw. (in Armstrong, Young & Robertson's Cat. West Scottish Foss., p. 6, Pl. II., Fig. 30.) The latter is a Hartfell species. The identity of the two forms can hardly be asserted at present as Lapworth's *calcaratus*, rests solely upon the figure of a basal fragment. Still, had I had access to his figure, I should not have described *D. trifidus*.

[24] Entirely overlooked by cataloguers. Horizon, from label on type in American Museum of Natural History, New York City. Locality, Turin, Lewis county, N. Y.

[25] Trenton Limestone of Wisconsin.

[26] I suspect that, as Prof. Whitfield (Mem. Amer. Mus. Nat. Hist., N. Y., 1895, I., pp. 40–41) believes, this genus is non-graptolitic.

[27] One species from the Trenton of Minnesota; three species from the Cincinnati group at Cincinnati, Ohio; all in the collection of Mr. Ulrich.

[28] "Lower beds, Cincinnati Group" (Ulrich; label).

[29] *Diplograpsis ruedemanni* Gurley, sp. nov.

(*Diplograptus pristiniformis*, Ruedemann, 1895, Amer. Jour. Sci., pp. 453–455, Figs. 2, 3; *Diplograpsis ruedemanni* Gurley, *nom. nud.*, supra, p. 78).

Entire polypary consisting of a number of diprionidian stems ("polyparies" as formerly understood) originating in and radiating from a common central "disk" (Ruedemann). Diprionidian stems quite small, the greatest length observed (in incomplete specimens) 7^{mm}. Maximum breadth 1.5^{mm} (a single stout specimen reached 1.75^{mm}). Thecæ cylindrical, the breadth practically the same throughout and their axis practically straight; 38–50 in 25^{mm} as nearly as determinable (ranging from 2 in 1^{mm}, 7 in 4^{mm}, 5 in 3^{mm}, to 3 in 2^{mm}). Aperture in scalariform impression, squarish, $0.6–0.8^{mm}$ on a side; margin straight, in the large majority of specimens appearing perpendicular to virgula, thus producing a deep indentation, a shorter overlap ($\frac{1}{3}$–$\frac{2}{5}$), and an acute "denticle." But I believe (the material not perfectly satisfactory) that the real condition is: margin inclined to virgula on proximal ("distal") side about 60° (say 55°–65°), and an overlap of ½. Inclination of the thecæ on proximal ("distal") side to virgula, 40°.

I know but six Diplograpses with as many thecæ in 25^{mm}, viz.: *D. sinuatus* Nich., and *D. insectiformis* Nich., both Upper Silurian species; *D. confertus* Nich., whose breadth (8^{mm}) alone suffices to exclude it: *D. putillus* (Hall), which has 34–38 thecæ in 25^{mm} without overlap; *D. minimus* Carr., with which the present species will bear comparison; and *D. hudsonicus* Nich. From the last *D. ruedemanni* differs in the form and amount of overlap of the thecæ and in lacking the spine on the lower lip of the aperture.

Horizon and locality.—Utica Shale, near Dolgeville, N. Y., dedicated to the discoverer, Dr. R. Ruedemann, of Dolgeville.

[30] *Fide* Whitfield (Rep. Wheeler Surv., 1875, IV., p. 19). I do not believe these genera occur in the Utica, and think with Lapworth, that the *Didymograpsus* was probably a *Leptograptus*. As in Britain the Glenkiln, so in America its equivalent, the Lower *Dicellograpsus* Zone, seems to mark the last appearance of the genus *Didymograpsus*.

SUPRA-ORDOVICIAN

Genus and Species	Upper Silurian		Devonian		Lower Carbon.
	Clinton	Niagara	Upper Heldbg.	Hamilton	Choteau
Diplograpsis? dubius[1]	SG				
Lomatoceras[2]	—				
clintonense	HG				
convolutum coppingeri[3]					
Gladiolites[4]	—				
venosus	HG				
Dendrograptus		—			
dawsoni		S			
dubius		S			
frondosus		S			
novellus		HG			
praegracilis		S			
ramosus		S			
spinosus		S			
Callograptus		—			
granti		S			
minutus		S			
multicaulis		S			
niagarensis		S			
Dictyonema	—	—	—	—	—
blairi					G
expansum		SG			
fenestratum			H		
gracile		S			
actinotum				HG	
pergracile		S			
pertenue	F				
retiforme		S			
scalariforme	F				
splendens					
tenellum		S			
websteri					
Desmograptus				—	
devonicus				HG	
Calyptograpsus		—			
cyathiformis		SG			
micronematodes		SG			
?radiatus		S			
subretiformis		SG			
Rhizograpsus		—			
bulbosus		S			
Acanthograpsus		—			
granti		SG			
pulcher		SG			
Inocaulis		—			
anastomotica		R			
bellus		HW			
cervicornis		SG			
diffusus		SG			

SUPRA-ORDOVICIAN—*Continued*

Genus and Species	Upper Silurian		Devonian		Lower Carbon.
	Clinton	Niagara	Upper Heldbg.	Hamilton	Choteau
Inocaulis—*cont'd.*					
divaricatus		H			
phycoides		SG			
plumulosus		HSG			
? problematicus		S			
ramulosus		S			
walkeri		SG			
Thamnograptus		?			
? bartonensis		SG			
Ptilograptus		—			
foliaceus		SG			
Cyclograptus		—			
rotadentatus		SG			

NOTES TO SUPRA-ORDOVICIAN TABLE.

F signifies *fide* A. F. Foerste.

G signifies *fide* R. R. Gurley.

H signifies *fide* James Hall.

HW signifies *fide* James Hall and R. P. Whitfield.

R signifies *fide* E. N. S. Ringueberg.

S signifies *fide* J. W. Spencer.

[1] I have examined a number of specimens of Spencer's *Phyllograptus dubius*. It is found merely as a black stain on the dark brown weathered Clinton shales. In regard to it I am willing to say only that the specimens appear to be mostly, and probably are entirely, Diplograptids. At least two (perhaps three or even more) species are present, as I found one which had the thecæ about 1^{mm} apart, and another about 1.5^{mm}. All the marginal fringing (which imparts somewhat the aspect of an *Inocaulis* branch) is due to weathering.

As regards the genus, there is little certainty, the specimens being very indistinct. *Phyllograptus*, of course, it cannot be and the present generic reference will probably prove to be the correct one.

[2] See p. 79.

[3] From Arctic America.

[4] See p. 79.

[5] Only two authors have, I believe, touched on the possible presence of Graptolites in the Carboniferous. Portlock (Geol. Rep. Londonderry, etc., 1843, pp. 321, 322) says: "The family of Graptolites has at present no known representative in the Carboniferous system; although a specimen from the mountain limestone, belonging to Captain Jones, M. P., has a strong resemblance to some of the double Graptolites."

And Hall (Pal. N. Y., 1859, III., p. 496) remarks that:

"The Graptolitidæ are therefore at this time clearly traced to the base of the Carboniferous system, and we may probably find allied genera to the close of the Palæozoic period."

In a collection presented to the U. S. National Museum, by Mr. R. A. Blair, of Sedalia, Mo., a *Dictyonema* was pointed out to me by Mr. Charles Schuchert, Curator of Palæontology. I have elsewhere described it as *D. blairi*. Associated with it are some poorly preserved specimens which bear, as Portlock would say, "a strong resemblance to some of the double Graptolites." I am, however, inclined to think it only a superficial resemblance, and pending further collections can assert the existence of no graptolite fauna other than *D. blairi*. Concerning that species there is no room for doubt.

COMPOUND AND SIMPLE FORMS IN THE DIPLOGRAPSIDÆ.

The recent paper of Ruedemann[1] unquestionably marks a real advance in our knowledge of *Diplograpsis* structure. Although I have not seen the specimens, I am prepared to accept the results described, as several years ago I saw a similar specimen on which a good many individuals of *Diplograpsis foliaceus* Murch., were so grouped as, on the doctrine of probabilities, to render it almost certain that they must have grown radiatingly from a common center. The specimen did not, however, show the common center. Since then I have seen a similar specimen in Professor Hall's collection which is still less equivocal. With better material Ruedemann has given a very interesting description of the structure, and has I think proved at least the following: That in two *Diplograpsis* species the stems ("polyparies," as we have been calling them) formerly regarded as simple and complete in themselves, are in reality only fragments of compound aggregates, relative to whose center the so-called "distally prolonged virgula" is in reality proximal, and the position of the sicula distal.

Such a discovery is to a certain extent revolutionary of our views of diplograptid structure, and is in importance comparable only to Hall's similar discovery of central connections for many of the numerous fragments previously lumped together as Monoprions and Monograpti on the easy "cells-on-one-side" character.

But (and this is the principal *raison d'etre* of this section) it seems to the writer that induction from these two *Diplograpsis* species to the *Diplograpsidæ* in general may be premature. And it is to the generalizations that Ruedemann has made (and very properly, indeed, from the standpoint of his material alone) that attention is directed.

The real question seems to be the magnitude of the taxonomic value of the discovery. In two *Climacograptus* species (*C. caelatus*, *C. phyllophorus*)

[1] Amer. Jour. Sci., 1895, pp. 453–455, Figs. 1–5.

an organ which from its position and character must be regarded as homologous with Ruedemann's "central disk" occurs. But in these species the "disk" is almost certainly simple, as it has a perfectly definite, uniform and constant outline. The compound form cannot then be taken as a family character. It may, however, prove of generic rank, *Diplograpsis* perhaps being distinguished by a compound, and *Climacograptus* by a simple disk. While it could be conceived as not even having this value, it seems to me not improbable that it may ultimately acquire this significance.

R. R. GURLEY, M.D.

U. S. GEOLOGICAL SURVEY.

STUDIES FOR STUDENTS.

DEFORMATION OF ROCKS.—II. AN ANALYSIS OF FOLDS.

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    The overturned normal synclinorium.
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As ordinarily treated, folds are considered as simple flexures in two dimensions. As they occur in nature, folds are complex flexures in three dimensions.

Folds in rocks may be compared with the waves of the sea. Each large wave has superimposed upon it waves of the second

order; upon these are waves of the third order, and on these waves of the fourth order, and so on. Moreover, running across the most conspicuous waves at various angles up to perpendicularity may be other waves of an equally composite character. As observed from a ship at sea the waves of the first order are so large and have such gentle slopes that they are often overlooked, while the steeper waves of the second order are noticed, because more conspicuous. On account of their small size the waves of a higher order than the second are usually unnoticed, as are also the waves of all orders which are transverse to the more conspicuous set.

If when stirred by a great storm the surface of the sea could in an instant be frozen, we should obtain some idea of the complexity of the waves. We should see primary elevations and depressions of circular, oval, and lenticular horizontal sections, in different sets, crossing one another in various directions, and upon these would be other sets of waves of like complexity of the second, third, and fourth orders, and so on.

The rock waves of the earth are of greater size and of equal or greater complexity than the waves of the sea. The rollers of the sea, when not wind forced may be compared with the long, gentle folds of rock. At first sight they seem simple, but, like the rock folds, when observed closely they are found to possess secondary crenulations. At the other extreme are the highly complex waves running in various directions at the same time, formed by the shifting winds of a great storm, by currents and tides together. The sea in this condition may be compared with the rocks in which each set of primary folds has superimposed upon them folds of the second order, and upon these those of a higher order to the *n*th order. The smaller orders of folds are microscopic. Such complex rock folds are called crumpled, plicated, or implicated.

In this comparison it is not meant to imply that the forces which produce rock folds are the same, or that they work in the same manner, as the forces which produce sea waves. Nor is it meant that the forms of the folds are the same as the forms of

the waves. The only purpose of the comparison is to give at the outset some idea of the complexity of rock folds.

Tangential thrust and gravity are assumed to be the causes of folds. No attempt will be made here to show this or to explain the cause of thrust, although in the last analysis it is probable that thrust is dependent upon gravity. At all times and in all positions rocks are subject to the force of gravity. Thrust and gravity act upon rocks of heterogeneous character. Rock heterogeneity, therefore, modifies the forms of folds. Folds are further modified by igneous rocks. In what follows, the effects of igneous rocks are at first excluded.

We shall now attempt to analyze the rock waves or folds. For convenience, they will first be considered in two dimensions.

SIMPLE FOLDS.

Simple folds are classified by de Margerie and Heim[1] as follows: A fold is upright or symmetrical when the axial plane is vertical, or nearly so, and the limbs have nearly equal dips in opposite directions at corresponding points (Fig. 1).

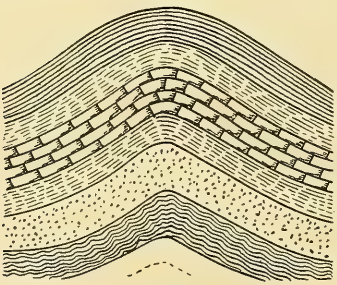


Fig. 1.—Simple upright fold.

A fold is inclined or symmetrical when the axial plane is inclined and the limbs have unequal dips in opposite directions at corresponding points (Fig. 2).

A fold is overturned or overfolded when the axial plane is inclined and the limbs have equal or unequal dips in the same direction at corresponding points (Fig. 3). An overturned fold is lying or recumbent when its axial plane is horizontal, or nearly so (Fig. 4). The different parts of an overturned fold are the arch limb, reversed limb, and trough limb (*a*, *b*, *c*, Fig. 4).

As to closeness of compression, folds are described by de

[1] Les dislocations de l'écorce terrestre, par Emm. de Margerie et Albert Heim, Zürich, 1888, pp. 49–63.

Margerie and Heim as follows: An ordinary fold is one in which the strata diverge from the crest of the anticline and the trough of the syncline (Figs. 2–4). Ordinary folds may be described as

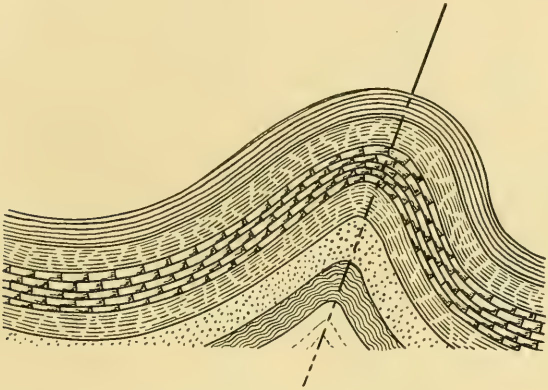


FIG. 2.—Simple inclined fold.

gentle, open, or close. In close folds, according to Willis, the process has gone so far that the strata are perceptibly changed in thickness in different parts of the fold. An isoclinal fold

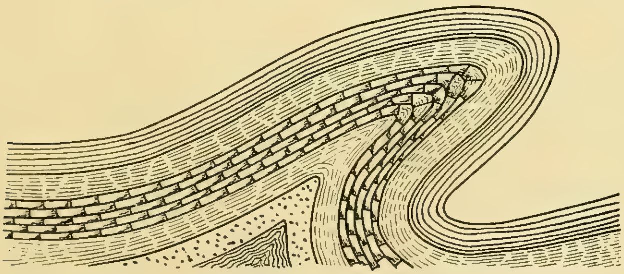


FIG. 3.—Simple overturned fold.

is one in which the strata are parallel, or nearly so (Fig. 5). A fan fold is one in which the strata converge downward from the crest of the anticline (Fig. 9), or upward from the trough of the syncline. In this case the strata at the limbs of the fold are always greatly thinned, and in some instances the central strata are absent, the material having flowed up and down, form-

ing detached arch cores and detached trough cores. An ordinary, isoclinal, or fan fold may be upright, inclined, or overturned.

In the formation of the simple fan-shaped anticline the

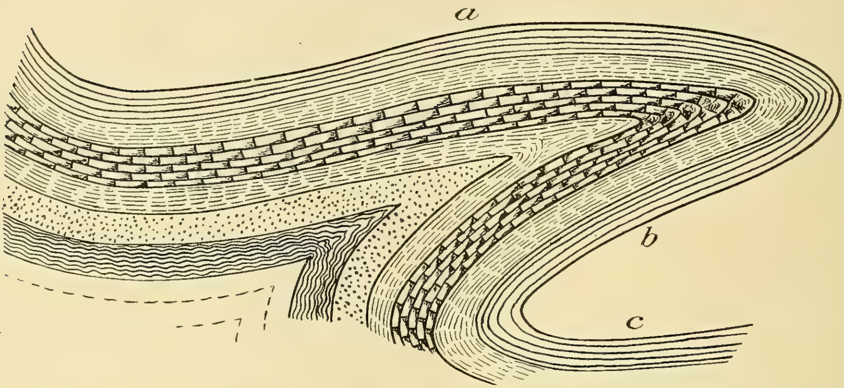


FIG. 4.—Simple recumbent fold.

rocks are extremely compressed on the limbs of the fold, while on the anticline the compression is not so severe. This is doubtless due to the partial escape from pressure of the material which

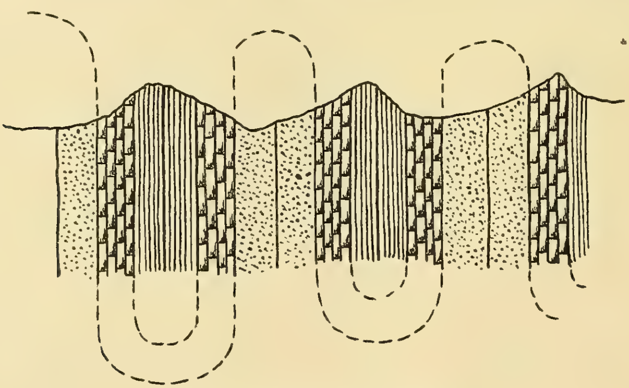
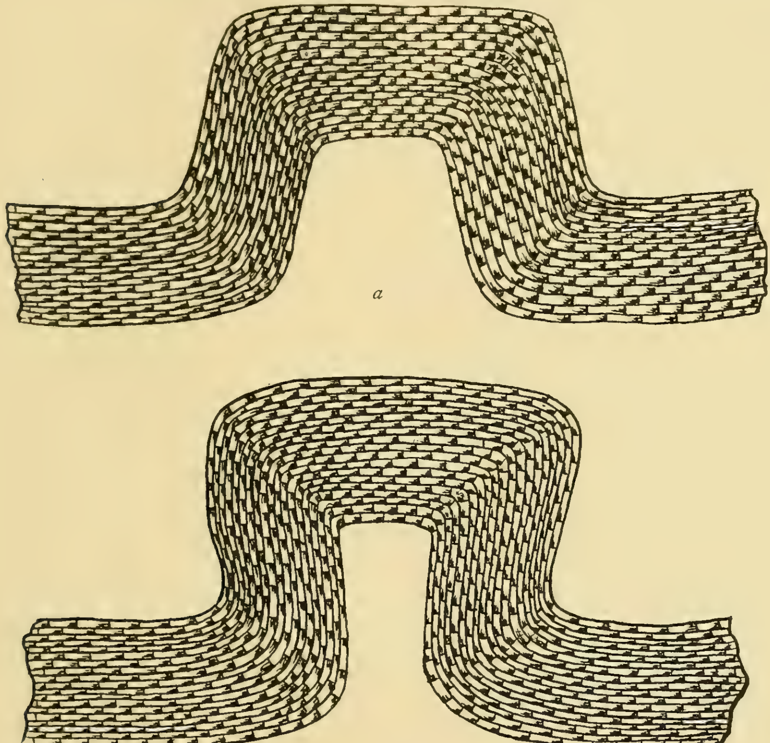


FIG. 5.—Simple isoclinal folds.

rises into an arch, as compared with the deeper-seated material in the limbs of the folds, which constitutes a part of the continuous crust of the earth in which the major thrust must have been transmitted. Another factor is the relative strength

of the layers. A strong stratum may deform weaker layers, geologically below, into the fan form by producing flowage in them. The formation of the fan fold may be further assisted



b

FIG. 6.—*a*, Diagram of fold in limestone of the Jura Mountains, showing hinge-like bending at sides of anticlines: *b*, the same somewhat more closely compressed, so that the fold has become fan-shaped.

by the tendency of rocks to bend farther at a place where deformed rather than to bend in a new place. The different phases of the formation of fan folds are illustrated in the Jura. In the folds of certain parts of the Jura one is impressed with the flatness of the anticlinal domes and the synclinal troughs, the steepness of the limbs, and the rapidity of the change from flat dips at the anticlines and synclines to nearly vertical dips on the

limbs of the folds (Fig. 6*a*). So quick is the change that the folds may be said to have corners, where the beds are bent in a circular fashion almost within their own radius. In the more closely compressed folds the beds constituting opposite limbs of the folds are overturned in opposite directions, thus producing a true fan fold (Fig. 6*b*). It is clear that the material of the domes partly escaped the thrusts which were transmitted in the solid rocks below. This thrust from both directions pressed the lower parts of the limbs closer and closer together, while the rigidity of the partly free dome above prevented the upper part of the legs from following, and thus the limbs were overturned in opposite directions. It is probable that the folds in the Jura represented by Fig. 6 were not very deeply buried, and that had the material been much deeper the more regular form of fan fold shown by Fig. 9, and characteristic of the Alps, would have been produced. It may be suggested that the Jura and the Alps belong to the same great geological province, and since the types of folding are the same in both mountain ranges it is not improbable that if the Jura were uplifted sufficiently and more deeply denuded the ordinary fan-shaped fold of the Alps would be revealed.

It follows from the above that the mechanics of the formation of fan-shaped synclines are not the same in all respects as those of the anticlines. It can hardly be assumed that synclines are of such magnitude that the lower parts reach a level in which the thrusts are less than at a higher level. In other words, it cannot be assumed that the lower part of the trough of a syncline is under less lateral compression than the center of the fold. This may, however, be the case if a "level of no strain" is so near the surface as two miles. Even if this supposed level is not at a greater depth than seven or eight miles, Davison's later estimate, the thrust may be considerably less at the deeper parts of the fold than at the places of greatest lateral force. We therefore do not know whether the first and probably the most important cause of the production of fan-shaped anticlines—difference in amount of thrust—may also apply to the produc-

tion of fan-shaped synclines. A difference in the strength of layers and a tendency for layers to continue to bend at certain places when bending has begun, rather than at other places, may tend to produce fan-shaped synclines. For instance, if a very strong layer is between two weaker layers, and this stronger layer becomes bent more decidedly at the outer, upper parts of the syncline, it may continue to bend at these places, and by its strength deform the softer material above and below it, so as to force the whole into a fan form. That minor fan-shaped synclines are thus produced is highly probable, but it may be doubted whether fan-shaped synclines of the first order would be thus formed, although they may be produced by differential thrust if the theory of a "level of no strain" be true.

COMPOSITE FOLDS.

The greatest flexures of the earth's crust are termed by Dana *geanticlines* and *geosynclines*. Generalizing from his illustrations, it appears that these may be defined as flexures which are predominantly due to the force of gravity in its tendency to produce isostatic adjustment. The deforming force is therefore mainly vertical. When rocks are subjected to strong lateral forces they are also deformed, and mountain ranges are produced. All folds, of whatever magnitude, thus made by the work of great lateral thrust and gravity combined, when not simple, are called, following Dana, *anticlinoria* and *synclinoria*. An anticlinorium or synclinorium of the first order of magnitude is one which comprises an entire mountain range. Illustrating this usage of the terms, the great geological province or basin of deposition of which the Jura, the great valley of Switzerland, and the Alps occupy a part, was a geosyncline. When subjected to orogenic forces the mountain ranges now seen were produced. The Alps and Jura, taken as wholes are anticlinoria of the first order, and the great valley between is a synclinorium of the first order.

The various kinds of simple folds may be united to produce a great variety of composite structures. A composite fold may be an anticlinorium or a synclinorium. An anticlinorium or

synclinorium, like a simple fold, may be upright, inclined, or overturned, but it is probable that in composite folds of the first order of magnitude the last rarely if ever occurs.

Taking as axial planes the radial planes of the primary fold, the secondary folds may be upright, inclined, or overturned, or on different parts of the same primary fold each form may occur. The radial positions of the axial planes give the proper basis in comparing the dynamic processes and effects of folding, but

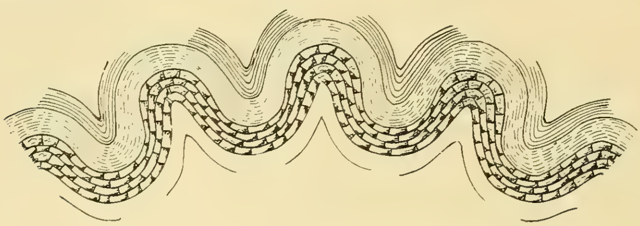


FIG. 7.—Ideal section of an upright normal anticlinorium.

because we rarely see the whole of a great anticlinorium or synclinorium at a single view, it is perhaps best to treat both the primary and secondary folds in reference to the plane of horizon.

Some of the special cases of composite folds are as follows:

NORMAL COMPOSITE FOLDS.

The upright normal anticlinorium.—The primary fold of the upright normal anticlinorium has a vertical or nearly vertical axial plane, and the limbs at corresponding points have nearly equal average dips in opposite directions.

(*a*) The primary fold is composed of a set of secondary folds each of which is upright or nearly so, taking the radial planes of the primary fold as axial planes of the secondary folds. Referring the axial planes to the horizon, at the crest of the anticline the secondary folds are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are inclined, but not overturned. The two sets of secondary axial planes on opposite sides of the crest of the primary fold diverge upward and converge downward (Fig. 7).

(*b*) Composed fan fold. The primary fold is composed of a set of secondary folds which at the crown are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are first inclined and then overturned. The secondary folds may be ordinary, isoclinical, or fan-shaped. The

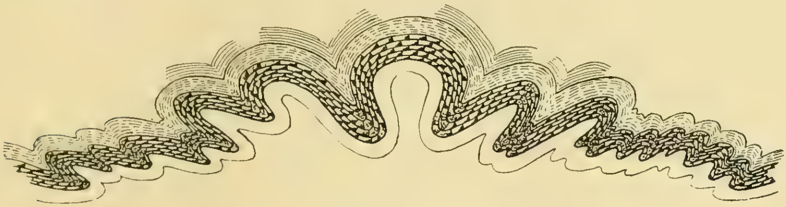


FIG. 8.—Ideal composed fan fold.

two sets of secondary axial planes on opposite sides of the crest of the primary fold diverge upward and converge downward (Figs. 8 and 9). Often in extreme cases of compression at

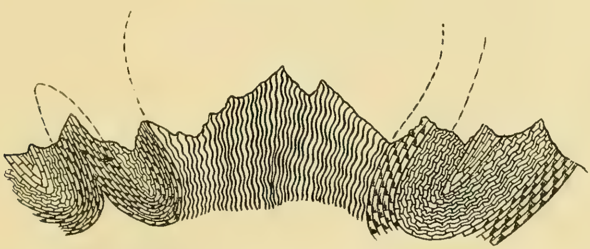


FIG. 9.—Generalized fan-fold of the central massif of the Alps. After Heim.

the crest of the primary anticline the secondary folds are fan-shaped, and passing in either direction these grade into isoclinal and then into ordinary folds. Such are many of the composite folds of the Alps.

The inclined normal anticlinorium.—The primary fold of the inclined normal anticlinorium has an inclined axial plane and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the crest of the

primary fold diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The overturned normal anticlinorium.—The primary fold of the overturned normal anticlinorium has an inclined axial plane, and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same

FIG. 10.—Ideal section of an upright normal synclinorium.

direction as the primary fold. The two sets of secondary axial planes on opposite sides of the crest of the major fold diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The upright normal synclinorium.—The primary fold of the upright normal synclinorium has a vertical or nearly vertical axial plane, and the limbs at corresponding points have nearly equal average dips in opposite directions.

(*a*) The primary fold is composed of a set of secondary folds, each of which is upright, or nearly so, taking the radial planes of the primary fold as axial planes of the secondary folds. Referring the axial planes to the horizon at the trough of the synclinorium, the secondary folds are upright, and in passing in either direction transverse to the primary axial planes the folds are inclined, but not overturned. The two sets of axial planes on opposite sides of the trough of the major fold converge upward and diverge downward (Fig. 10).

(*b*) Inverted intermont trough.[1] The primary fold is composed of a set of secondary folds, which at the center of the trough

[1] Les dislocations de Pécorce terrestre, par EMM. DE MARGRIE et ALBERT HEIM p. 83. Zürich, 1888.

are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are first inclined and then overturned. The two sets of secondary axial planes on opposite sides of the trough of the major fold converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped (Fig. 11).

The inclined normal synclinorium.—The primary fold of the

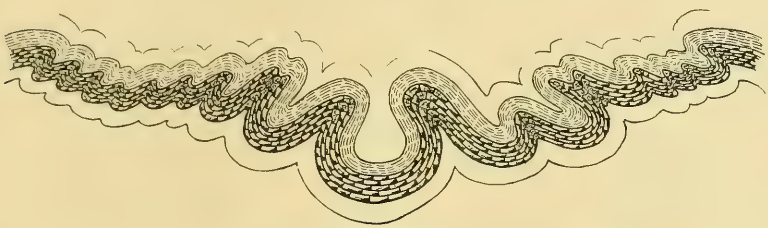


FIG. 11.—Ideal section of an inverted intermont trough.

inclined normal synclinorium has an inclined axial plane, and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds, which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the trough of the major fold converge upward and diverge downward. The secondary folds may be ordinary, isoclinal or fan-shaped.

The overturned normal synclinorium.—The primary fold of the overturned normal synclinorium has an inclined axial plane, and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same direction as the primary fold. The two sets of axial planes of the secondary folds on the opposite sides of the trough of the major fold converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

ABNORMAL COMPOSITE FOLDS.

The upright abnormal anticlinorium.—The primary fold of the upright normal anticlinorium has a vertical, or nearly vertical, axial plane, and the limbs at corresponding points have nearly

equal average dips in opposite directions. The primary fold is composed of a set of secondary folds, which at the crest are upright, and in passing in either direction transverse to the

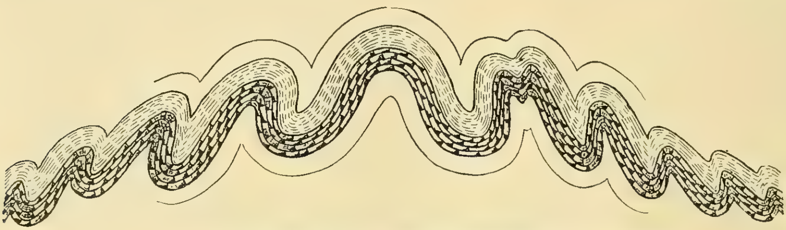


FIG. 12.—Ideal section of an upright abnormal anticlinorium.

primary axial plane the secondary folds are first inclined and then overturned. The two sets of secondary axial planes on opposite sides of the crest converge upward and diverge down-

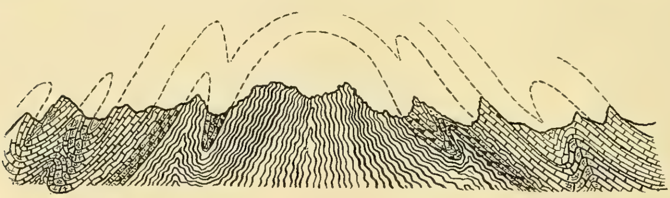


FIG. 13.—General section of roof structure in the central massif of the Alps. After Heim.

ward. The secondary folds may be ordinary, isoclinal, or fan-shaped (Figs. 12 and 13).

The inclined abnormal anticlinorium.—The primary fold of the inclined abnormal anticlinorium has an inclined axial plane, and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds, all of which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the crest converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The overturned abnormal anticlinorium.—The primary fold of the overturned abnormal anticlinorium has an inclined axial plane,

and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same direction as the primary fold. The two sets of secondary axial planes on opposite sides of the crest converge upward and diverge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

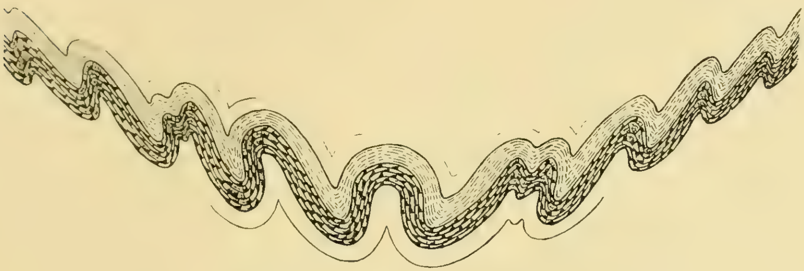


FIG. 14.—Ideal section of an upright abnormal synclinorium.

The upright abnormal synclinorium.—The primary fold of the upright abnormal synclinorium has a vertical, or nearly vertical, axial plane, and the limbs at corresponding points have nearly equal average dips in opposite directions. The primary fold is composed of a set of secondary folds, which at the trough are upright, and in passing in either direction transverse to the primary axial plane the secondary folds are first inclined and then overturned. The two sets of secondary axial planes on opposite sides of the trough diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped (Fig. 14).

The inclined abnormal synclinorium.—The primary fold of the inclined abnormal syclinorium has an inclined axial plane, and the limbs at corresponding points have unequal average dips in opposite directions. The primary fold is composed of a set of secondary folds, all of which are inclined or overturned. The two sets of secondary axial planes on opposite sides of the trough diverge upward and converge downward. The secondary folds may be ordinary, isoclinal, or fan-shaped.

The overturned abnormal synclinorium.—The primary fold of the overturned abnormal synclinorium has an inclined axial plane, and the limbs at corresponding points have equal or unequal average dips in the same direction. The primary fold is composed of a set of secondary folds, which are overturned in the same direction as the primary fold. The two sets of secondary axial planes on opposite sides of the trough diverge upward and converge downward.

OCCURRENCE AND ORIGIN OF COMPOSITE FOLDS.

Higher orders of folds.—In all of the above cases the secondary folds of the primary anticlinoria and synclinoria may themselves be anticlinoria and syclinoria. The tertiary folds of the secondary anticlinoria and synclinoria may also be anticlinoria and synclinoria, and so on to the *n*th order. The higher orders of the anticlinoria and synclinoria are microscopic. Each higher order of anticlinorium and synclinorium may be described with reference to the anticlinorium and synclinorium of the next lower order in a manner similar to the description of the primary anticlinorium and synclinorium with reference to a simple fold of the first order of magnitude.

Even in regions of gentle folding, looked at in a large way, anticlinoria and synclinoria are the rule rather than the exception. In regions of moderately close folding the secondary anticlinoria and synclinoria, as a rule, are themselves anticlinoria and synclinoria. However, it is in such regions as the Alps, Canada, eastern United States, and Lake Superior that occur the complex anticlinoria and synclinoria composed of folds of different orders up to the *n*th order.

The primary anticlinoria and synclinoria are usually upright or slightly inclined. The higher orders of anticlinoria and synclinoria are usually inclined or overturned. The very large synclinoria and anticlinoria on the flanks of the massifs of the Alps, in the Green Mountains of Massachusetts, the southern Appalachians, and many other mountain ranges, many of them miles in length, are to be considered as secondary folds composing a

part of the primary anticlinoria, each of which includes a central massif and both its flanks. By an examination of the published transverse sections of the Alps and Green Mountains (see Fig. 19) it will be seen that they are usually complicated fan-shaped anticlinoria, which are composed of complex normal and sometimes abnormal anticlinoria and synclinoria. In each normal anticlinorium, of whatever order, the axial planes of the folds of the next higher order diverge upward and converge downward, while in each normal synclinorium the axial plane of the folds of the next higher order converge upward and diverge downward. In the abnormal anticlinoria and synclinoria the reverse is the case.

Origin of normal folds.—As has been stated, the forces which act upon rocks when being folded are assumed to be tangential thrust and gravity. In the smaller folds, thrust may be thought to be the dominant force, the other being the modifying force of varying strength. In the great folds of the earth, gravity may be thought to be the dominant force, which by differential depression relatively raises a great anticline or depresses a great syncline, while thrust may play a subordinate part, being the dominant force in the production of folds of the second and higher orders. In folds of intermediate size, each of the forces may be about equally important. The relative value does not matter so far as the foregoing analysis is concerned, as in all three cases the resultant forms fall within the classes given. As long as we are so far from agreeing upon the forces which produce mountain ranges, and their manner of work, it seems best to classify the forms of folds as we find them, and to explain their origin so far as we are able. If thrust and gravity be conceived as acting uniformly upon horizontal homogeneous rocks, which are under such conditions as to bend without breaking, normal anticlinoria and synclinoria will be produced. Because of initial dips (as explained by Willis), or unequal superincumbent weight, or other causes, or one or more of these together, rocks when subjected to thrust and gravity rise into an anticline here or fall into a syncline there. But there is unequal weight upon

the different parts of each anticline and syncline. The large basins of deposition are not simple, but undulating. These secondary undulations are composed of smaller ones, and so on until ripple-marks are reached, and even these are composite. Each curve is composed of rhythmical curves of a higher order; hence the arch or trough which forms is not simple, but is composed of a number of minor folds, and these again of those of a higher order.

At first the anticlinorium is upright, or nearly so, as are also the folds of a higher order which compose it, but the secondary folds on the flanks of the primary fold point slightly outward, although the accommodations between the beds compensate in part for this (Figs. 15 and 16). As the limbs of the anticlinorium become steeper the secondary folds on the limbs are thrown farther and farther away from the axis of the primary arch (Fig. 7). If unaffected by other forces, when the primary fold becomes steep the secondary folds on the limbs become much inclined or overturned. When the limbs of the primary folds become vertical, the secondary folds on the limbs become lying or recumbent. In all cases, therefore, the axial planes of the secondary folds diverge upward and converge downward. The force of gravity may enter to further modify the forms of the folds. When a fold is inclined, its own weight and that of the superincumbent beds tend to push it over still farther. The effectiveness of gravity in this work is doubtless in part due in many cases to partial escape from thrust because of the relative rise above the deep-seated beds largely transmitting the horizontal force. (See p. 318). The farther the secondary folds are inclined, either by the increased steepness of the primary fold or by the effects of superincumbent weight, the more effective is gravity in pressing them down still farther (Fig. 8). When the weight of the superincumbent material is great, these folds may be pressed into a recumbent position, even where the primary anticlinorium is a gentle fold. Thus are explained the composite normal anticlinoria of the Alps.

At first a synclinorium is upright, or nearly so, as are also the

folds of the next order which compose it, but the secondary folds on the primary fold point slightly inward, although the accommodations between the beds compensate in part for this (Figs. 15 and 16; see p. 331). As the limbs of the synclinorium become steeper the secondary folds on the limbs are thrown farther and farther toward the axis of the primary trough. If unaffected by other forces, when the primary fold becomes steep the secondary folds on the limbs become much inclined or overturned. When the limbs of the primary fold become vertical, the secondary folds on the limbs become lying or recumbent. In all cases, therefore, the axial planes of the secondary folds converge upward and diverge downward. But the force of gravity enters to further modify the form of the folds. When a fold is inclined, its own weight and that of the superincumbent beds tend to push it over still farther. The effectiveness of gravity in this work is doubtless in part due in many cases to partial escape from thrust because of the relative rise above the deep-seated beds largely transmitting the horizontal force. (See p. 318.) The farther the secondary folds are inclined, either by the increased steepness of the primary fold or by the effects of superincumbent weight, the more effective is gravity in pressing them down still farther (Fig. 11). When the weight of the superincumbent material is great, these folds may be pressed into a recumbent position, even when the primary synclinorium is a gentle fold. In the synclinoria on the flanks of the Alps, which are secondary to the great primary anticlinorium, the crests of the recumbent secondary folds sometimes nearly meet, thus almost closing the synclinorium.

The question may be raised as to the effectiveness of superincumbent weight in pressing down inclined folds. It has been explained [1] that zones of folding of rock masses are necessarily zones of readjustment or of partial rock flowage. The flowage is from the places of great compression to the places of less compression. Where the weight of the superincumbent strata is so great as to equal or surpass the strength of the rocks folded, it appears

[1] This JOURNAL, Vol. IV., pp. 209–212.

clear that gravity must be an important force, which may greatly modify the forms of folds. The particular form of fold in a given case is of course the resultant of all the forces which work upon the rock stratum composing it.

So far as I am aware, Dana,[1] in 1847, was the first geologist to call attention to the principle that folds may be modified by the force of gravity. As is well known, this idea has been recently emphasized by Reyer.

Origin of abnormal folds. — In the abnormal anticlinorium and synclinorium new factors enter to modify the result. The first is readjustment between the beds. Fig. 15 represents a draw-

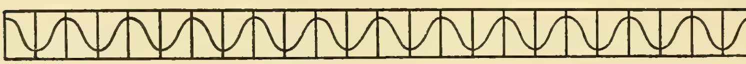


FIG. 15. — Representation of simple symmetrical folds, with their axial planes drawn on the ends of a bunch of smooth paper three-fourths of an inch thick.

ing of a number of upright folds made upon the ends of a bunch of smooth sheets of paper three-fourths of an inch thick. The sheets may be taken to represent thin beds in a nearly homogeneous rock. Fig. 16 represents this same drawing as it was distorted when the bunch of paper was folded into anticlines and synclines between blocks of wood. It will be seen that, consequent upon the readjustment of the sheets over one another, rendered necessary by the folding, the secondary folds at the crests and the troughs remain upright, although compressed if a secondary anticline or syncline corresponds with a primary fold of the same kind, and dilated if a secondary anticline or syncline corresponds with a fold of the opposite kind, and vice versa. If the secondary folds were slight, the opening might go so far as to obliterate them and the only remaining effect be to flatten the primary anticlines or synclines. The secondary folds on the limbs of the primary folds are distorted. The readjustment therefore mainly affected the forms of the fold upon the limbs. Taking as their axial planes the radial planes of the primary

[1] Geological results of the earth's contraction in consequence of cooling, by JAMES D. DANA, Am. Jour. Sci., 2d ser., Vol. III, p. 185, 1847.

folds, the secondary folds on the limbs are seen to be inclined. In reference to a primary anticline, the axial planes of opposite folds converge downward; in reference to a primary syncline, the axial planes of opposite folds diverge downward, but both less than they would were it not for readjustment. The above experiment does not exactly represent the conditions in nature, for the accommodations between the beds, instead of occurring parallel to the primary folds, would take place parallel to the secondary folds. However, an examination of the distortion of the axial planes of Fig. 15, shown in Fig. 16, shows beyond question that

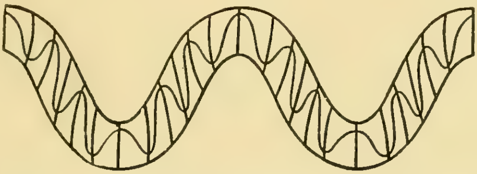


FIG. 16. — The same, as it was distorted when folded into anticlines and synclines.

when a set of beds is folded which are free to adjust themselves parallel to bedding, the movement of the material in the upper half of the beds is relatively away from a syncline toward an anticline, and the movement of the lower half is away from an anticline toward a syncline; or, stated more generally, the differential movement between any two adjacent beds on the legs of folds is relatively up in the higher bed and relatively down in the lower bed. It cannot be doubted that the sum total of the readjustments between the beds, although they follow the crenulations instead of being exactly parallel to the primary fold, would give the same effect. Therefore there is a tendency in anticlinoria and synclinoria, due to normal differential movement, for secondary folds to become inclined, taking the radial planes of the primary folds as axial planes of the secondary folds. However, when the readjustment is uniformly distributed this tendency does not so far affect the secondary folds but that they fall within the class of normal composite folds. But if the major readjustment of a great set of formations were largely concentrated along a

single one in it, anticlinoria might have the axial planes of the secondary folds converge upward and diverge downward, and synclinoria might have the axial planes of the secondary folds diverge upward and converge downward, and thus both become abnormal. This readjustment along the beds, as explained in my paper in the following number, may in many cases be considered as movements along shearing planes.

The second new factor in the production of abnormal folds is the great strength of the older rocks. For a given region, upon the average, rocks become stronger with increase of age. There are innumerable exceptions to this if too small portions of geological time be compared, as period with period, but comparing era with era such exceptions are rare or altogether absent. The Archean rocks are usually stronger than the Proterozoic, the Proterozoic rocks are stronger than the Palæozoic, the Palæozoic rocks are stronger than the Mesozoic, and the Mesozoic rocks are stronger than the Cenozoic. This in the sedimentary strata is due to the indurating effects of various geological forces. In mountain ranges, where complex anticlinoria and synclinoria mostly occur, a great thickness of strata is concerned in the major folds, in most cases more than the deposits of an era; so that upon the whole in great mountain masses the lower groups of rocks are stronger.

The third cause of the production of abnormal folds may be decreasing lateral stress with increasing depth. That such variation in stress is a general fact must be true if the theory of the level of no lateral stress at a moderate depth be correct. It has been pointed out (pages 210–212) that folds must die out with increasing depth unless there is great rearrangement of material. If it be supposed that the opposing stresses upon opposite sides of an anticline or syncline decrease with depth, there will certainly be more decided folding of the higher strata than of the lower. This implies upward differential movement of a higher stratum as compared with a lower beyond that required for normal readjustment. (See p. 331). Consequent upon this there will be a tendency for the axial planes of secondary folds on

anticlinoria to diverge downward, and for those on synclinoria to converge downward.

Another factor in the production of abnormal composite folds is the position of the fold in the group of rocks folded. The farther the rocks are below the surface the greater is the weight of superincumbent strata and the more forceful is gravity in pressing to a recumbent position the inclined secondary and tertiary folds of great anticlinoria or synclinoria. As has been seen, the inferior strength in the upper strata and the lessened weight to which the upper strata are subjected are not usually sufficient to prevent thrust and gravity from acting in the ordinary way and producing normal anticlinoria and synclinoria.

In both the abnormal anticlinorium and synclinorium the application of the above causes to their formation are identical. To make this clear the following figures are drawn: Figs. 17 and 18 each represent four strata, the lower two of which are strong and the upper two of which are weak, each figure comprising one-fourth of a wave and the other being its complement. In each case the figure ends on one side at the crest and on the other at the trough of the flexure. There is nothing to indicate whether either is a part of an anticline or a syncline. Each, in fact, may be half of either, for, put end to end in one way, they form an anticline; in the other, a syncline. In both cases the lower rocks constitute a relatively rigid inclined plane. If the superincumbent weight is not too great when thrust occurs, in certain cases the softer rocks above may yield to the forces to a greater degree than do the rigid rocks below, and thus tend to flow over them, and in case the upper strata be much weaker than the lower, or there be a plane of weakness, the differential flow will be largely concentrated along the contact or weak zone, and normal secondary folds which have before developed may be inclined in an opposite direction from their first position, so as to become abnormal. This case is represented by the middle parts of Figs. 17 and 18. Put together end to end in one way the prominent secondary folds form an abnormal anticlinorium; in the other, an abnormal synclinorium. It will be noted that

in passing away from the central zone of plications either into the more rigid rocks below or into the softer rocks above the secondary folds become normal. Considering the two figures put together to represent a great flexed mountain mass, and supposing erosion to truncate the layers to the horizontal line drawn, there would be exposed normal folds at the center of the anticline, abnormal ones upon the flanks, and normal ones at the outer parts of the mountain mass. In nature we can never hope to see such a great composite fold in all its parts. It is only in the great mountain masses where such folds have been dissected that we can get at their character. In such cases the older and newer strata would be expected to show the normal forms, the intermediate strata the abnormal forms. The change from normal to abnormal and to normal again is apparently that which actually occurs in the Alps from the St. Gothard massif south to the great valley of Switzerland.

The manner in which the more rigid rocks escape large plications while the weaker beds are strongly plicated, producing abnormal folds, is well shown by Fig. 13, given by Heim as a general section showing roof structure in folded sediments and a central massif. In the production of actual abnormal anticlinoria and synclinoria it is probable that accommodations as illustrated by Figs. 15 and 16 are largely concentrated as illustrated by Figs. 17 and 18. Therefore the production of abnormal anticlinoria and synclinoria may be summarized as follows:

When two groups of rocks of unequal strength, not deeply buried, are folded into an anticline, on account of the natural readjustment of strata, of the relative weakness of the upper, newer group of rocks, and probably of decreasing differential stress with increasing depth, there may be differential flow on either side toward the axis of anticlinorium over the lower, older rocks, thus producing secondary folds, the axial planes of which converge upward and diverge downward. Had the rocks been of equal strength, or had the weight of the superincumbent strata been sufficient to more than overbalance the difference in strength and difference in stress tending to produce folds point-

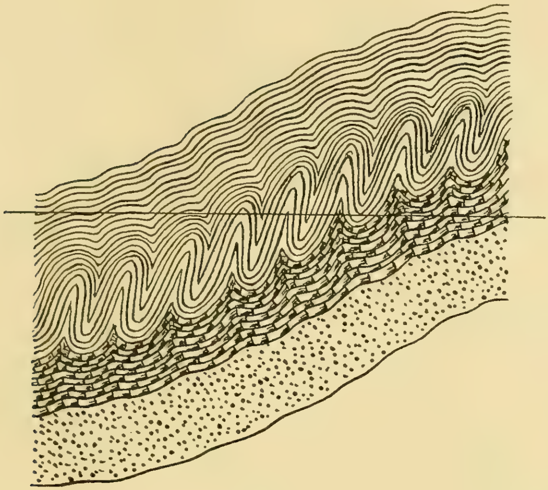


FIG. 17.

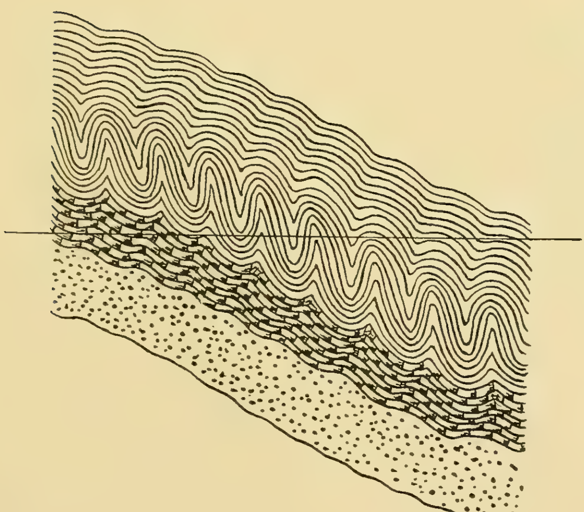


FIG. 18.

FIGS. 17 and 18.—Observe halves of composite folds, showing development of abnormal folds and their relations to normal folds.

ing crestward, normal secondary folds pointing outward would have developed.

When two groups of rocks of unequal strength, not deeply buried, are folded into a syncline, on account of the natural readjustment of the strata, of the relative weakness of the upper, newer group of rocks, and probably of decreasing differential stress with increasing depth, there may be differential flow of the rock material on either side away from the axis of the synclinorium over the lower, older rocks, thus producing secondary folds, the axial planes of which diverge upward and converge downward. Had the rocks been of equal strength, or had the weight of the superincumbent strata been sufficient to more than overbalance the difference in strength and difference in stress tending to produce folds pointing troughward, normal secondary folds pointing inward would have been developed.

Crystalline or core rocks are apt to be more massive and stronger than the little altered sedimentary beds, and therefore the core rocks usually act to a certain degree as a unit when subjected to thrust. Secondary abnormal folds are frequently found at the contact of massifs and the overlying rocks. However, even in these cases the folds will be normal if only the thickness of the superincumbent beds be sufficient. At a considerable depth the different strength of rocks is not so potent as gravity in giving form to folds. From the above it does not follow that the massifs or portions of them do not take part in the folding. That they do in many regions is certain, as is shown by infolding of core rocks with sedimentary beds, even when the massifs were originally granite. Also that massifs may take part in the folding is shown by the minor and major folds of their parts, which in form are like those of the associated sedimentary rocks.

It is recognized, however, as explained upon a subsequent page, that massifs, because of their homogeneous character, because they are underlain by no definite stratum of rock of a different character, and because they are often so deeply buried, may act in quite a different fashion, under the forces of folding, from ordinary sedimentary layers.

Causes modifying the forms of folds.—The foregoing discussion has been carried on as though the active forces of deformation are equal in opposite directions, and are acting in the same zone from opposite sides of the deformed area. If this were the case if the strata affected were of the same thickness and strength, if the initial dips were equal in opposite directions, and if the other conditions were the same, a strictly symmetrical arrangement of folds might be expected. But these conditions are never true. In the great majority of cases the facts do not depart so far from them but that the folds which form fall within some of the classes given. However, there are a number of ways in which the forms of folds may be modified.

Major faulting may interfere with their forms. Minor slip-faulting, as explained upon a subsequent page, may dominate an entire area. Igneous intrusions may disturb beds in many ways. Where these modifying causes are found the structure is the resultant of all the movements.

Finally it often happens that there is a tendency for the axial planes upon one side of an anticlinorium or synclinorium to be steeper than those upon the other. In some cases the axial planes of all the folds throughout a mountain mass may be inclined in the same direction. Such folds may be called *monoclinal*. In such cases the force, and consequently the movement of the strata, have usually been supposed to be more largely from one direction than from the other, and the axial planes of the folds have usually been regarded as dipping toward the force.

Various explanations have been offered as to how the forces act upon the strata in the actual production of monoclinal folds. Of these explanations, that offered by Rogers appears most probable for piles of strata of like rigidity. Believing as he did that the folds of the Appalachians were analogous to the waves of the sea, he naturally concluded that the tendency to a southeastward inclination of the folds of the Appalachians was due to the fact that the center of disturbance and resultant waves came from the southeast. While not following him in his explanation of folds as great waves suddenly formed, the idea seems reason-

able that the "forward thrust operating upon the flexures . . . would steepen the advanced side . . . precisely as the wind acting upon the billows of the ocean forces forward their crests and imparts a steeper slope to their leeward sides."[1] For we now regard folded rocks as plastic when bent. The compressive stresses do not extend to an indefinite depth, but are limited by the level of no lateral stress. They therefore affect the outer skin of the earth, just as does the wind the superficial water of the ocean. As a result there is a differential movement due to friction, the amount of movement upon the average gradually decreasing below the zone of maximum movement. Of course the sums of the forces, including friction are always equal in opposite directions, but they constitute a vertical couple, *i. e.*, "Two equal and parallel forces opposed in direction, but not in the same straight line." As a result there is differential movement of the material of the upper zone as compared with the lower, the former being thrust over the latter.

Other things being equal, where the differential thrust is greatest the first inclined fold is formed. The folding piles up the strata. After a time the increased thickness of material is sufficient to present a larger total resistance to deformation than the thinner strata in advance. This stress will then be transmitted forward. On account of the greater stress per unit of area, a second fold, similar to the first, will then be formed, but this results in again thickening the mass subject to the force couple, and again the stress is transmitted forward. A new inclined fold is then produced, and so on.

It is not necessary that one inclined fold shall be completely formed before others begin to develop. Indeed, this is not to be expected, for as soon as any thickening of the deformed mass occurs the conditions are favorable for the forward transmission of the effective stress. Thus many folds may be in process of formation at the same time and so far as I can understand,

[1] On the Physical Structure of the Appalachian Chain, as exemplifying the laws which have regulated the elevation of great mountain chains generally, by W. B. ROGERT, Proc. Assn. Am. Geol. and Nat. for 1840–2, p. 512, Boston, 1843.

there is no reason why differential movement should not be initiated at the same time wherever the conditions are favorable throughout the area in which monoclinal folds are observed.

It is to be noted that, under the assumption that the effective stress moves the upper strata over the lower, the vertical component of deformation is upward rather than downward. In other words, it is in the direction of easiest relief, and this is the kind of deformation one would expect, and which doubtless prevails in the majority of movements of the first order, in which thrust is the dominant force, for it has been seen (p. 332) that, upon the average, rocks are stronger with increasing age, and hence, there is greater resistance centerward than surfaceward, Folds thus produced by upper differential movement may be called "overthrust folds." The axial planes dip toward the effective stress, hence *overthrust folds are those in which the axial planes dip toward the force producing them.*

While the development of overthrust folds is the general law, it may not infrequently happen that under favorable conditions beds or formations may be thrust forward and downward. Folds thus produced by downward differential movement may be called "underthrust folds." The axial planes dip away from the effective stress, hence, *underthrust folds are those in which the axial planes dip away from the force producing them.*

In the rocks of a system or group strong formations may be above weak formations. In this case the strong formations are able to transmit the forces to a greater degree than the beds above or below. As pointed out by Willis, a forward downward movement may be directed by initial dip, and thus underthrust folds be produced. In a second case the strata pile up as a result of the folding. The relatively raised masses may then to a certain extent escape active thrust. (See Fig. 6 and p. 318.) The strata largely transmitting the thrust in front of the folded material may under these conditions be pushed under the higher mass. Underthrust folds are most likely to occur if the two conditions above given favorable to their formation are combined, *i. e.*, weak formations below and piling up of strata.

In considering the force couples in normal and abnormal composite folds, each composite limb between trough and crest must be separately analyzed. (See Figs. 17 and 18.) In normal anticlinoria and synclinoria gravity has been seen to be the efficient force which causes differential movement (pp. 328–330). Gravity works down the slope. The axial planes of the secondary folds dip toward the force (see Figs. 8 and 11), and the secondary crenulations are therefore overthrust folds. In abnormal composite folds it has been explained (pp. 330–333) that the differential movement may be caused by (1) normal readjustment, (2) increased strength of the rocks with increasing depth, and (3) the possible decreasing lateral stress with increasing depth. The first of these is eliminated for the present purpose. The second and third, either singly or together, must be sufficient to overcome gravity and to give a resultant force directed up the slope, in order that abnormal folds may be formed. (See Figs. 12 and 14.) The axial planes therefore dip toward the force, just as in normal composite folds, and the secondary crenulations are therefore overthrust folds.

By the above it is not meant to imply that underthrust folds may not be produced in either normal or abnormal composite folds, for if the conditions given on previous pages favorable for underthrust folds locally occur, crenulations of this type may be formed.

The formation of monoclinical folds is sometimes well illustrated by the crenulations of a lava bed in which there was differential flow down a slope, the upper layers moving faster than the lower. Monoclinal folds thus formed are usually not large. The directing force was gravity, and the axial planes dip toward the force. The crenulations are therefore overthrust folds. Since ordinary folds, which form without fracture, develop in the deep seated zone of flowage, the analogy with contorted lava currents is believed to be closer than might be at first thought, although it is not meant to imply by this that the folded rocks are really fluid, but merely that a plastic solid under sufficient differential stress is deformed in the same fashion as is a viscous liquid.

It has been pointed out (p. 331) that in ordinary folds the movement is relatively up for a higher stratum as compared with the one next below it. In the case of overturned monoclinal folds (Figs. 3 and 4) the later differential movements of the strata on the longer limbs of the folds may continue quite to and past the crests of the anticline, so that the differential movement on the shorter limbs of the folds is relatively down for the superior stratum geologically as compared with the inferior. However, in this case, when the folds are overturned, with reference to the horizon on the inverted limb, the movement of the higher stratum would still be upward, as compared with the one below it. This may be called *reverse differential movement*, and it may continue so as to more than compensate for the normal differential movement, but the resultant differential movement would be less on the steeply inclined or overturned limbs of the folds than on the longer, flatter limbs, since on the latter the motion is continuously in the same direction.

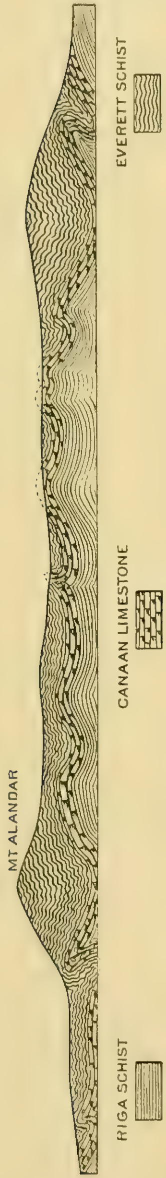


Fig. 19.

In the case of monoclinal folds it will be shown in my paper in the following number of this Journal that the shearing is greater on the longer, more gently inclined limbs than on the shorter, more steeply inclined limbs. As a result of this the former are not so thick as the latter and are usually more metamorphosed.

Examples of composite folds.—In the United States, Mount Greylock, the Taconic range, and the valley between constitute a great normal anticlinorium. The same is true of Mount Washington, in Massachusetts (Fig. 19). A cross-section of the central part of the Marquette district furnishes an example of a great abnormal

synclinorium. The abnormal character is due to the very great difference in strength between the Archean granite and the Algonkian Lower Marquette formations. At the east end of the Marquette district, where the Archean rocks are relatively weak schists, the synclinorium is normal.

Limit of term fold.—By the above analysis and examples it is not meant to imply that, where sediments were deposited off a land area and the land and sea areas were afterwards compressed, producing undulations in the sedimentary rocks, and often in those also of the original land areas, the terms anticlinorium and synclinorium are properly applicable to the primary flexures. Following Dana, as indicated on a previous page, such flexures are more properly described as geanticlines and geosynclines. In such cases, however, there is a differential uprising or subsidence, in many cases producing a composite flexure. It is believed that the principles applied to primary folds of true anticlinoria and synclinoria apply to the secondary folds in question. just as though they together constituted a part of an ordinary fold. When gravity controls their form they are normal. When the difference of strength of the rocks controls their form they are abnormal.

As a matter of fact, it is often difficult to determine in a given mountain range whether the so-called core rocks were deeply buried under a great thickness of sediments, being, perhaps, in or near the center of the trough of deposition, or whether they were, and continued to be, land areas. It is thought that it is one of the advantages of the treatment given that it is not necessary to decide this question before working out the structure of the district. In either case the types of flexures of the second and higher orders formed on the primary flexures and the laws controlling them are the same.

Movements continuous or discontinuous.—Composite folds may be the result of forces acting continuously or discontinuously. The different secondary folds may develop at different times. The higher orders of folds may begin to form only at a late stage of development. Usually it is impossible to determine whether

thrust was continuous or discontinuous. However, if the intervals between the successive movements were sufficiently long and the conditions were such that crevices could be formed and these were filled with secondary minerals, or if cementation or metasomatic changes produced new minerals, or if within the strata igneous rocks were intruded, the later dynamic effects upon such new material may enable us to determine the fact of different movements.

In the Hiwassee section of the Ocoee series, in the southern Appalachians, in the more closely folded part of the section, quartz veins have formed in a first set of crevices. The rocks have been subsequently folded so as to closely plicate these veins, and after this folding a second set of unfolded quartz veins has formed. In other parts of the section only unfolded quartz veins are seen. This shows that certain parts of the area were affected by two periods of folding separated by a long interval.

COMPLEX FOLDS.

ORIGIN OF COMPLEX FOLDS.

Thus far folds have been considered in two dimensions only and have been treated as though they were continuous and had continuous axial lines, each one being a great circle of the earth. Such is not the case in nature. In a given fold, in passing from place to place, the direction and inclination of the crest-line are different, and it is rarely, if ever, a part of a great circle. Its deviation from the horizontal at any point gives the inclination of the fold at that point. This inclination, measured in degrees, is known as the pitch. Also when a fold is followed longitudinally, or in the third dimension, it changes continuously in size and character. A fold of the greatest magnitude may be followed along the third dimension until it dies out. The most closely compressed and intricately composite fold may be followed in the third dimension until it becomes a gentle composite fold or even disappears. When a primary fold is traced in the third dimension it may be found to grade into a secondary fold. At the same time a secondary fold on the flank of a primary fold

may itself become the primary fold. On any fold a new secondary fold may appear, and when followed longitudinally may become more and more important until it is the dominant fold. In short, in a composite set of folds each fold of any order is constantly changing in character and importance.

In a given fold all of the changes may occur, and thrust may have acted only in a single direction. The initial dip of the beds may have been different. The thickness and strength of the beds may have varied from place to place. Thrust may not have been equal along the border of the entire area affected. It may not have continued to act as long in one place as in another. Therefore there is great variation in the character and size of folds at their different cross-sections. Gravity is always toward the center of the earth; therefore variation in its direction does not enter as a modifying force.

Further, in the foldings of rocks thrust is rarely, if ever, in a single direction. Usually, when complex thrusts are decomposed in two directions at right angles to each other, one is more powerful than the other. The greater force may be called the major thrust, and the lesser force may be called the minor thrust.

Major and minor thrusts may unite in a resultant effect and produce a set of folds in a position intermediate between those that the two sets would have if each thrust had been alone. It is possible and even probable in many cases, that after a thrust in one direction has produced a set of folds, a new thrust at an angle less than a right angle to the first may be decomposed into two forces and result in further folding the first set of folds, and perhaps in the production of transverse folds, rather than in producing a new diagonal set; for when rocks are once bent in a given place they bend farther much easier at this place in the same direction than at a new place in a new direction. This principle is well illustrated by the folds of the Jurassic limestone of the Jura Mountains (Fig. 6). The transverse component of the lateral thrust may be too weak to produce any considerable effect. In such cases it would be difficult or impossible to discriminate a set of folds thus formed by two diverse thrusts from a set

formed by simultaneous or successive thrusts in a uniform direction. However, if there be sufficiently strong thrusts in two or more diagonal directions, or two thrusts at right angles, two sets of folds are produced which intersect each other. Such a district may be described as one of complex folding. The more important set of folds, corresponding to the major thrust, may be called the major or longitudinal folds, and the cross folds, corresponding to the minor thrust may be called the minor or transverse folds.

CHARACTER OF COMPLEX FOLDS.

From analysis, as well as from observation, it is found that cross folds are usually nearly at right angles to each other ; for as already explained, if the diverse thrusts be inclined to one another, they will be resolved into two forces, one of which forms the major folds, and the other of which produces cross folds in a direction at right angles, or nearly so, to the first set of folds.

Major and minor cross folds may be produced by continuous forces in both directions, or in each direction each force may be continuous or discontinuous. To ascertain these points the same criteria are available as in the case of thrust in a single direction (see pp. 342–343).

Longitudinal and transverse folds may each be classified into upright, inclined, or overturned. Each of these may be ordinary, isoclinal, or fan-shaped. Simple folds may unite to form composite folds. The composite folds may be normal or abnormal, and each synclinorium or anticlinorium under each class may be upright, inclined, or overturned.

As complex folds actually occur in the field, usually the compression is not close in both directions. Cases are known, however in which a set of longitudinal overturned folds have transverse folds with vertical dips, and the dips of the transverse folds in intricately folded districts are in many cases as steep as 45° or 60°.

When the major folds are close, as compared with the minor folds, the complex folds have great length as compared with the breadth and are canoe-shaped. The Appalachians in the closely

folded districts may be taken as a type of such complex folding. That initial dip is not sufficient to explain the pitch of the folds in this region is shown by the following facts: A stratum or set of strata may rise at one end of a synclinal canoe. Beyond this for a distance the strata are removed by erosion, but farther on appear again plunging downward at the end of another canoe. Corresponding phenomena are observed in reference to anticlines.

In proportion as the major and minor thrusts approach each other in power, the canoes become shorter and broader. Where they are nearly equal the folds are domes and basins. Usually these domes and basins are associated with canoes, which may be in one or two directions in the same region. Where the two sets of cross folds are about equally conspicuous the strikes and dips of the rocks vary constantly, their directions depending upon what part of the complex folds is under observation.

Where the complex folds are also composite the canoes, domes, and basins are fluted or crenulated, being composed of secondary canoes, domes, and basins. Similarly, these may be composed of canoes, domes, and basins of the third order, and so on.

OBSERVATIONS IN COMPLEXLY FOLDED DISTRICTS.

From the relations of cross folds, as above explained, it is clear that where there are complex folds the axes of one set of folds and their pitch give the direction and dip of the cross fold at that point. Therefore to fully understand a district complexly folded it is necessary to make the following observations:

(1) Determine the strike and dip of the strata at a given point. These give the resultant position of the strata as tilted by the forces of folding in both directions.

(2) Determine the direction and pitch of the axes of the major folds. The first is the direction of dip and the second is the amount of the dip of the minor or cross folds. The average strike is, therefore, determined.

(3) Determine the direction and pitch of the axes of the minor folds. The first is the direction of dip and the second the

amount of the dip of the major folds. The average strike is, therefore, also determined.

Of these three observations, the first is the only one ordinarily taken, and it is the one of the least importance in regions of close, complex folding. It is only by making the second and third observations that an adequate idea of the structure can be obtained. While the first observation may be made at any point, the second and third observations can be made accurately only along the crests of the anticlines or troughs of the synclines of the various orders of folds. Therefore, it may be necessary tc work over a considerable area in order to obtain the required data. Some practical suggestions may be offered as to the manner of determining whether or not the rocks of a district are complexly folded, and if so folded, the direction and pitch of the axes of each set of folds, and therefore the strikes and dips of the two sets of cross folds.

(1) It is advisable to look for the ends of canoes. These may be frequently found at the ends of ridges; hence especial study should be made of the folds where a topographic break appears across the ordinary ridges, either at a right or an acute angle. When once the end of a canoe is found, an observation can be made as to the direction and pitch of the axes of the fold, and thus the strike and dip of the cross fold be determined.

(2) The tops of ridges should be examined. These may be the crests of anticlines or the troughs of synclines, depending upon the topographic development of the region. Along the little cross breaks which are sure to occur, the direction and pitch of the axes of the folds may be determined. In some instances ridges are longitudinally inclined, following hard layers, and in this case there is an exceptionally fine opportunity to determine the direction and pitch of the folds.

(3) In case the two sets of cross folds are about equally conspicuous, there may be a double set of ridges and valleys cutting each other at right angles, or nearly so, and this may give a clue to the character of the folding of the district.

(4) In some cases the beds are closely plicated in one direc-

tion so as to give nearly uniform strikes. Unless closely observed it may not be noted that there are really minor rapid deviations of strike, which indicate a set of pitching folds, and a complexly folded district. The major and more important folds may be transverse to the minor plications. From what has gone before, it is plain that in such cases the important observations are not the strikes and dips of the strata of the minor folds, which vary momentarily, but the direction and pitch of the axes of the minor folds, which give the direction and amount of the dip of the major fold, and therefore the average strike.

(5) Pumpelly has called attention to the fact that discordance between strike of bedding and that of secondary structures indicates pitching folds. Where a secondary structure develops at right angles to the greatest normal pressure, or nearly so, it in many instances has a nearly uniform direction for an extensive area. In case the folds are horizontal, or the district is simply folded, this direction is the same as the strike of the rocks or the strike of the axes of the folds. Where the forces producing the folds are in two or more directions, and consequently form complex folds, the minor component, producing pitch, does not develop cleavage at right angles to itself; and the relations between the strike of bedding and that of the secondary structure vary from near parallelism on the limbs of the longitudinal folds to a direction at right angles to each other at the ends of the canoes and on the crests of the anticlines and in the troughs of the synclines. In passing from one place to the other there are found all relations between parallelism and perpendicularity. Because the area where the two are parallel, or approximately so, is greater than the area where there is an important discordance between the two, it has been customary for text-books to speak of the strike of bedding and the strike of cleavage as usually parallel. This, as has been seen, is wholly true only where the folds are horizontal, and the statement becomes more and more a partial truth as the pitch of the folds increases in amount—that is, as the less conspicuous folds become more important. Hence it is that where a secondary structure exists the relations which

obtain between its strike and that of bedding should be ascertained, and if discrepancies are found this indicates a complexly folded district.

(6) Pumpelly also formulated the principle that "The degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications on its sides." This statement must be understood to apply to the direction and pitch of the primary fold at the point where the secondary fold is observed. This principle is a direct corollary from the relations of cross folds as given on a previous page, and it is of the greatest service in determining the structures of very complexly folded districts, because in them minor plications are so numerous. They may be seen in their entirety, and may therefore give the required determination of the character of the cross folds. The principle is, however, only approximately true. It would be wholly true if the secondary folds upon the flanks of the primary fold were exactly of the same character as the latter. But since the forces locally vary in direction and amount, and the rocks vary in rigidity, the direction and pitch of a secondary fold may vary somewhat from those of a primary fold. Usually this deviation is so small that the principle is invaluable in field work in regions of complex folding, and gives data of sufficient accuracy for ordinary purposes.

It is evident that in the application of all the above criteria we must consider bedding and not secondary structure. The criteria upon which this discrimination is made will be considered in a later paper.

Very often in regions of complex folding observers note only the most conspicuous folds in a single direction. The fact that folds are composite may be overlooked, and that they are complex is even less likely to be seen. The difficulty is further increased because of faults and secondary structures, such as slatiness, schistosity, and banding, which may be mistaken for bedding. The development of these structures and their relations to folds and bedding will be considered in following papers.

In ordinary districts where there are cross folds the more

conspicuous set is generally chosen as giving the direction of folds, while the less conspicuous set in the other direction is considered as giving the pitch of the folds. It does not follow that the folds giving the pitch, in the magnitudes of their vertical components, are less important than the more conspicuous longitudinal folds, for the lowness of the dips of the transverse folds may be more than compensated by their greater lengths, and the cross folds may be of the first order of magnitude in a district. Usually it is possible to work out the structure of such a district without particular attention being directed to transverse folds. They are so gentle that the changes of strike and dip are not rapid, and a satisfactory map may be made without recognition of the existence of cross folds. It is suspected that the largest folds of a district have often escaped the attention of the geologists who did the mapping.

The more complex the folding of a district the more necessary it is in determining its structure to consider the character of both sets of folds, and for very complex districts this is imperative.

By means of maps and sections it is difficult to represent the structure of a very complexly folded district, and even a dissected model does not represent it completely, as it is impossible to show in true porportion the different orders of folds, and especially those of the higher orders. It is plain that cross-sections in a single direction at long intervals fail to give any adequate idea of the structure of such a district, although these combined with geologic and topographic maps may do so. In reports the structure can best be represented by combining the geologic and topographic maps with two sets of cross-sections made at frequent intervals and at right angles to each set of folds.

It will be noted that in the foregoing treatment of folds they are classified as they occur, no ultimate theory of their origin being offered. No conception of the causes of mountain ranges enters into the analysis. It is true that an explanation is attempted of the difference between normal and abnormal composite folds. The fact that this explanation apparently accords

with the forms and distribution of folds in all of the many different districts to which it has been applied, and at the same time accords with the principles of mechanics, appears to me to give to it a considerable degree of probability. Even if the explanation be not accepted, the forms of folds and the principles applicable to their study remain the same. Thus we have a classification of folds and an outline of methods for their study which will assist in determining the structure of the complexly folded districts and in preparing areal maps of them.

CHANGES ACCOMPANYING FOLDING.

Contemporaneous with rock folding, and in a large measure dependent upon it, other changes occur in rocks. As has been seen, crevicing and brecciation largely depend upon the same forces as does folding.. During the process of folding old minerals are transformed into new ones. New mineral material enters from the outside. The minerals are rearranged and mechanically modified. Secondary structures, such as cleavage fissility, joints, and faults may develop. In short, during the folding process the rocks are to a greater or less degree metamorphosed.

RELATIONS OF FOLDS AND UNCONFORMITY.

The folding of a set of inferior formations in a more compli cated manner than that of another set of superior formations may indicate a structural break between the two, and consequently that the two sets of formations belong to different series. In order that this criterion may be applied, it must be conclusively shown that the supposed upper formations are really above the others. It must not be assumed that a formation at one side of an axis of plication is in a superior position because less folded, for in many regions close folds die out within a comparatively short distance in a direction transverse to them. This is the case along the Green Mountains, where the closely folded Lower Palæozoic rocks pass quickly, to the westward, to unfolded or very gently folded ones. The change here takes place so rapidly that it has been supposed by many geologists that the more closely

folded rocks are really the older and belong to a series prior to their unfolded westward continuation. The failure to appreciate the above principle has been to a large degree the cause of the Taconic controversy.

It is believed that the cause of the frequent sudden change from closely folded to very gently folded rocks across the strike of the folds is due to the principle explained on pages 317–318. This is: Strata when once bent at a certain place continue to bend at this place rather than to form a new fold. This bending continues until, as a result of the folding, the strata are greatly thickened and the inclinations become steep, so that resistance to further folding at this place is greatly increased. The force is then transmitted forward and a new area is affected by folding, but as soon as the strata are here bent they continue to bend easily until they are closely folded, so that there is the same sudden transition as before from the closely folded to the very gently folded or unfolded districts.

In the first and simplest case the lower formations have been subjected to either simple or complex folding, while the upper formations are undisturbed or very slightly disturbed. In this case the upper formations are likely to be found as inlyers upon the other, and the structural break between the two is comparatively easy to determine. Phenomena of this kind are found at many localities between the Palæozoic and pre-Palæozoic sediments, and less frequently they are found wholly within the pre-Palæozoic formations.

The second case is that in which the lower formations were folded by one or more movements before the upper series was deposited, and subsequently the two were again folded. If the second folding was of a comparatively simple character, and the earlier was rather complex, it is usually comparatively easy to separate the two series. For instance, the lower formations may have been rather closely folded by the first orogenic movement, and the two sets of formations together may have been gently folded by the second movement. The discrepancy between the two may often be detected, even when the movements were in

the same direction, as they so frequently were. But the discordance may be more easily discovered if the second movement was in a different direction from the first, so that the first folds of the lower formations become complexly folded at the second period of folding, the newer formations at the same time being simply folded.

Third, in more complicated cases the lower formations were folded one or more times before the upper series was deposited, and after the deposition of the latter the two series were again folded in a complex fashion, either by a single orogenic movement or else by successive movements. In proportion as the folding of the later formations becomes complicated the criterion of folding for separating series is more and more difficult to apply, and where the folding of the upper formations is at all intricate it is usually of little value. The criterion of folding for separating uncomformable series is to be considered in all cases in connection with other criteria.

C. R. VAN HISE.

EDITORIAL.

THE preparation of thin sections of rocks, is an art, in which few have suceeded. It appears to require patience in reducing the sections at the proper rate, and delicacy of touch in finishing them. Those of us who study rocks with a microscope are aware how seldom rock sections are prepared of the desired thinness for optical investigation. Too often the section has been left unfinished, so that the more minute crystals present a confused aggregation of indeterminable parts. There is no doubt that the difference between good and bad petrographical work is due in many cases to differences in the quality of the thin sections studied. Sections thin enough to permit the feldspar and quartz to display only the lowest gray interference color, and which reveal the minutest textures in microcrystalline or glassy rocks, are essential to satisfactory work

The petrographers connected with the United States Geological Survey have been fortunate in this respect, having been furnished with exceedingly well made rock sections, prepared for the most part by Hermann Ohm and Frederick C. Ohm. The former has left with many of us the memory of a skilled and honest worker, who won our respect and friendship; while the latter has earned an equally high place in the esteem of those who look to him for the preparations by means of which they forward their special investigations. It is not too much to say that a large part of the pleasure and satisfaction which the writer has derived from his petrographical researches is due to the excellency of the thin sections made by these workers.

It is gratifying to learn that Mr. F. C. Ohm has started his son in Washington in the business of making rock sections, and that he will be able to supervise the finishing of them and can guarantee the character of the work. It is to be hoped the son will become as expert as his father, and that the undertaking will prove successful, since it will be of great benefit to students of petrography throughout the country to have the opportunity of obtaining thoroughly satisfactory rock sections. J. P. I.

Reviews.

Geological Biology, an Introduction to the Geological History of Organisms. By H. S. Williams. Henry Holt & Co., 1895.

Of late years numerous books on evolution have appeared, but perhaps none have been more practical or suggestive in their treatment of the subject than the present volume by Professor Williams. The subject matter of the book was originally presented in the form of lectures, delivered first at Cornell University and later at Yale. These lectures were intended to supplement a laboratory course in palæontology, by suggesting the most vital lines of thought in the actual interpretation of fossils considered as the records of the history of organisms. In the preparation of the matter for publication the lecture form has been dropped and the material so revised as to serve the general reader as well as the student.

It is evident that the biologist proper, who deals alone with contemporaneous organisms, must rest with a theoretical interpretation of the laws of evolution. The actual records of the history of organisms are found in the fossils preserved in the rocks and it is the purpose of the author to point out the chief facts and factors of evolution as shown from a study of the fossils.

In beginning the study of any history some system of chronology must be adopted. In the early chapters of the book the author discusses the development of the geological time-scale as now generally adopted, passing from the earliest classification of rocks based on their original order of formation, through the second stage in which the classification was based on their mineral constituents, to the present classification based on their fossil contents.

Fossils represent the hard parts of living organisms, or those parts which have attained definite and fixed form during the life of the organism. "The history of organisms, which we particularly trace in the study of fossils, is not the history of imperfect organisms struggling towards perfection, but it is the history, for each age and epoch, of the perfected adjustment of the organisms of the time to the particular

conditions of environment in which they lived. They did not die before their time, overcome by the mythical fittest who are said to survive in the struggle. They were the fittest, and died natural deaths, having provided before they gave up the struggle for their progeny to succeed them. The hard parts record the history of adults which have endured the struggle, and thus represent the royal line of succession for the geological ages."

Evolution is a fundamental law in the geological history of organisms. The "morphological differentiation (*evolution*) is as characteristic of the history of organisms in geological time as organic growth (*development*) is characteristic of the history of the individual organism in its lifetime." With the progress of time the morphological characters assumed by organisms have been gradually and incessantly changing from the beginning. This constant change or evolution is a fundamental law of organisms. Inorganic things on the contrary are unchangeable. The chemical composition and properties of things are the same as far back as we can trace them. A quartz crystal formed in Archæan time has exactly the same form with exactly the same angles as a crystal of the same substance formed today.

A certain analogy between ontogenesis and phylogenesis is commonly recognized. As each individual has a life history, so also has each species, genus, family, etc., but this fact must be emphasized, that in the individual development a *change of function* is associated with the several stages of ontogenesis; while it is difficult to imagine any corresponding change of function in the successive representatives of a common race. For this reason great caution is necessary not to force the theory of correspondence between the ontogenetic stages of functional activity and the order of differentiation of new characters expressed in the phylogenetic history of organisms. The two series of phenomena present this marked contrast, that in ontogenesis each phase of development is a repetition of phenomena which have been repeated in the same way from the beginning of organic life, while in phylogenesis each step is a step in advance of anything that has occurred before.

Evolution and adaption are both observed facts. The continuous morphological change of organisms, coördinate with the progress of time, is evolution. In this onward progress of organisms they are everywhere locally adapted to the particular environment in which they are placed. This adaptation to environment is brought about

through the action of natural selection, but this adaptation is not the evolution nor is natural selection the cause of evolution, but only one of the factors in the process of evolution. A first cause of some sort is essential to any complete theory of evolution.

"Among those today who adopt evolution as the explanation of the mode of origin of the different forms of organisms, there are two extremes of opinion with many intermediate compromises.

"All will agree in recognizing ancestry and environment as each taking some part in the evolution; but the extreme school, on the one hand, holds that *environment* is the chief factor determining the direction and extent of the modifications, which heredity tends to perpetuate, and that ancestry plays only the part of holding and preserving, in its offspring, what it gets from the agency of environment.

"The other extreme is the opinion that *ancestry* is the more efficient factor in bringing about the evolution; that in what is called *variability* there is working out, not a mere accidental reflex of environment upon the plastic organism, but a fundamental property or force of organisms, ever tending from homogeneity to heterogeneity and resulting in the specialization of functions and the differentiation of organic structure always; the line of evolution followed out by any particular race being influenced little by environment,—the adjustments being active and not passive, — the successful organisms seeking and adopting conditions favorable for their existence if out of them, dying out if the conditions favorable are not within reach, or if crowded out of them. Natural selection to this school of opinion plays rather an eliminating rôle than one of causation, and explains rather why there are gaps in the series of organisms than why the characters assumed in the modified forms are what they are. In this latter view the successive steps of modification of a race are as much controlled by the ancestry as are the successive steps of development in the growth of the individual.

"In the former view there is the replacement of the theory of immutability of species by that of the mutability of species, but the process of reproduction is still looked upon as immutable, reproducing the characters of the parents in the offspring without change; in the second view reproduction itself takes a part in evolution and normally accomplishes modification of form, either slowly or suddenly, but progressively, and evolution is an intrinsic law of organism."

Mutability of species is the central thought in the new theory of the origin of species. Darwin first clearly announced that *species are*

mutable, and as the whole science of natural history was constructed on the idea of their immutability, a complete readjustment of the science has resulted. With the revolution of thought started by Darwin's "Origin of Species," came a new conception of the nature of species. "The change was a philosophical one; no longer was the species considered to be a permanent entity with definite boundaries, but in the definition of organic species its time-relations and its geographical distribution were elements added to those of its morphology and physiology. This was a great advance. The organism came to be recognized not as a mere concrete being independent and standing by itself, constituted at the beginning what it is and remaining so during its existence, but as a very dependent part of a greater organism, nature itself, and related intimately with its surroundings or environment, to the organisms which preceded it or its ancestry, and to those which are to follow it or its descendants, as a sensitive, slowly changing reflex of all that has been and is. In the new conception there is the dim outlining of the idea (an old idea, but one which is day by day growing more distinct and of fuller comprehension) that nature itself is a greater organism in which the species is but one of the organs."

The problem of the origin of species came to be a question for scientific investigation, only when the old idea that variations were not cumulative, but were always simply variations, was superseded by the newer idea that variations are cumulative, and that reproduction is not a process of exact but of inexact repetition of characters. Variability is thus assumed to be an inherent characteristic of all organisms. The natural inference from the Darwinian explanation of the origin of species is that characters appearing first as varieties are through continuous repetition in the process of generation, gradually elevated to specific, generic, family, etc., rank. Palæontologists are inclined to doubt the fact of natural selection playing such an all-important part in the evolution of organisms. Cope has expressed the idea that evolution of generic characters has progressed in a different way, and has developed the idea of the law of acceleration and retardation which acts in association with natural selection but independent of it. There is assumed to be a special developmental growth force which is exhibited in variation itself and which becomes effective, as phylogenetic evolution, through acceleration and retardation. The Darwinian or natural selection school of evolutionists is engaged in accounting for

the acquirement of permanence of originally variable elements, while the Neo-Lamarkian school is engaged in accounting for the variability itself.

The laws of evolution as illustrated by the life-history of the brachiopoda are fully discussed by the author. The evidence obtained from this class of organisms points to the fact that the evolution of those characters which mark the differences between separate classes, orders, suborders and even families of organisms, has taken place in a relatively short period of time; taking as a measure either the rate of general progress in the differentiation of organisms, or the length of the life period of each particular genus or family. This rapid evolution is difficult to account for by any working of natural selection. Two factors are at work in the process of evolution which are designated as intrinsic and extrinsic evolution. "*Intrinsic evolution* is conceived of as normal expansion and differentiation of the organism itself from within, and is the expression, in some way, of an intrinsic tendency of the particular race of organisms. The other, *extrinsic evolution*, expresses the limitation and selection exerted upon the organism from without."

Illustrations of the laws of evolution are further drawn from other classes of organisms as the Cephalopoda and Vertebrata. From all these illustrations it is pointed out that the geological evidence does not emphasize the importance of natural selection as a factor in evolution. The following paragraphs may be quoted as setting forth the views of author.

"That which has seemed most conspicuous to the latter class of observers (students of living organisms) has been the intimate relationship existing between morphological difference and environmental conditions; palæontological facts point to the greater importance of the continuous and progressive process of differentiation and specialization of structure and function with the passage of geological time.

"The facts examined . . . . . show that evolution is rather an intrinsic law of organisms, and is to be discovered in the phenomena of variation, which appear to be constantly active, rather than in any accidental operations dependent upon the conditions of external environment.

"Evolution is seen to be a process that is primarily organic; it is expressed in the acquirement of new characters in the course of growth by living organisms; and we may as reasonably speak of evolution as

of the growth force of the individual or the force of gravitation. As the normal laws of growth of the individual are thwarted and diverted by external conditions, so undoubtedly a greater or less modification of the course of evolution has been produced by the conditions of environment.

"When we attempt to explain the course of evolution by tracing it backward from the differentiated, adjusted organisms to its ancestors, it is natural to place great importance upon the fact of the accomplished adjustment of the individual to its particular environment; but when the point of views is reversed and the organism is traced from the earlier geological periods through the ages down to the present time, the conviction becomes impressed upon the student that environmental conditions are but the medium through which the organic evolution has been determinately ploughing its way." S. W.

Canadian Fossil Insects. By S. H. Scudder. Contributions to Canadian Palæontology, Vol. II., Part. 1 (1895).

This publication includes three different papers by Prof. Scudder.

1. *The Tertiary Hemiptera of British Columbia.* Descriptions are given of nineteen species from three different localities—Quesnel on the Fraser, the north fork of the Similkameen River and Nine Mile Creek flowing into Whipsaw Creek, a tributary of the Similkameen. Dr. Dawson considers the two latter localities to be portions of a single ancient lake, so only two basins are concerned. The two basins afford specimens of very different character and may prove to represent different stages in the Tertiary. The age of the beds is probably as old as the Oligocene.

The great diversity of this ancient insect fauna may be judged from the fact that in nearly every case each specimen must be referred to a distinct species, and in only one case can two species be referred to the same genus. The most striking feature of the fauna is the large size of the individuals which compose it.

2. *The Coleoptera hitherto found fossil in Canada.* Fossil Coleoptera have been found in seven distinct localities at three very different horizons, viz., Post-Pliocene, thirty-two species, lower Tertiary, fourteen species, and Cretaceous, one species.

The most interesting fauna is that from the inter-glacial deposits of

Scarboro' Heights, near Toronto where twenty-nine species have been found. Not one of these can be referred to existing species. The nearest allies of several are to be sought in the Lake Superior and Hudson Bay region, but the nearest allies of the larger part of them are to be found in the general district where the deposits occur. In no single instance have any special affinities been found with any characteristically southern form, though several are most nearly allied to species found there as well as in the north. On the whole the fauna has a boreal aspect, though by no means so decidedly boreal as one would anticipate under the circumstances.

3. *Notes upon Myriapods and Arachnids found in Sigillarian stumps in the Nova Scotia coal field.* Nearly fifty years ago Sir J. W. Dawson and Sir Chas. Lyell first called attention to this unique land fauna of Carboniferous time. From time to time additional species of Articulates, Mollusks and Vertebrates have been discovered and described by Sir J. W. Dawson. The present paper by Professor Scudder gives notes and descriptions of ten species of myriapods and arachnids, some of which are new. S. W.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.

MATTHEW[1] gives the following pre-Cambrian succession near St. John, N. B.:

A.—Laurentian.

1. *Portland group*, including Division 2, with probably parts of Division 1 in other localities than St. John.

2. *Intrusive granite* and quartz-diorite; perhaps later than the position here assigned to it.

B.—Huronian.

3. *Coldbrook group* or Div. 3, of volcanic rocks.

4. *Coastal group* or Div. 4, of volcanic and sedimentary rocks, in its upper part probably equivalent to the next group.

5. *Etcheminian or Basal Series*, of sedimentary rocks, underlying the St. John group.

6. *Kingston group* or Div. 5, of metamorphosed volcanics. Of very uncertian relations; may be post-Cambrian.

The Huronian in southern New Brunswick is in large part made up of surface volcanic rocks. The lower part or Coldbrook group is almost exclusively volcanic; the upper part or Etcheminian is clastic, while the intermediate Coastal contains both volcanic and sedimentary members. The effusive rocks include lavas, breccias, and tuffs, and with them may be placed a holocrystalline soda-granite which is probably either an intrusion or a very thick surface flow.

The Etcheminian series rests unconformably upon the Coldbrook series and unconformably below the St. John group, which is for this district placed at the base of the Cambrian. The igneous rocks comprise effusives, including quartz-porphyry, felsite-porphyry, diabase, and feldspar-porphyrites, and dike rocks, which include diorite-porphyrite, diabase, and augite porphyrite. Each of these is described in detail.

Bailey[2] gives a preliminary report upon southwestern Nova Scotia. The oldest rocks here found are those of the Cambrian system, in which there is the following succession from the base upward:

[1] The Effusive and Dyke Rocks near St. John, N. B., by W. D. MATTHEW, Trans. N. Y. Acad. Sci., Vol. XIV., 1895, pp. 187–217, Plates XII.–XVII., Figs. A. B.

[2] Preliminary Report on Geological Investigations in Southwestern Nova Scotia,

1. Quartzite Division.
   (*a*) Heavily bedded blue quartzites, with slightly plumbaginous partings, alternating with numerous but much thinner beds of gray argillite. In metamorphic areas the quartzites become more micaceous, assuming the aspect of fine-grained gneisses, while the finer beds become glistening mica-schists.
   (*b*) Greenish-gray sandstones or quartzites, less massive than in (*a*) and alternating with slates which are arenaceous below, but become gradually more argillaceous above.
2. Slate Division.
   (*a*) Greenish-gray slates, becoming bluish or light gray, and passing into purple slates, or becoming clouded or zoned with shades of green, purple, blue, buff or pale yellow, often producing a conspicuous ribbanding of the beds. The occurrence of light yellowish-green seams is a characteristic feature of the purple slates.
   (*b*) Bluish-gray and blue slates, with lighter gray seams or bands, and including in places an upper zone of purple slates.
   (*c*) Black, with some blue or gray slates, often highly pyritiferous. In metamorphic regions the green slates are represented by chloritic and hornblendic schists (or locally by conglomerates with a micaceous or hornblendic base); the slaty beds by micaceous, garnetiferous, and andalusitic schists.

Above the Cambrian rocks are those belonging to the Devonian system. There are several important areas of granite, as follows: Those of South Mountains, Blue Mountains, Tusket Wedge, the Barrington area, Kelvin area, and Port Mouton area. These are intrusive within the Cambrian, and in places they clearly penetrate and alter the fossiliferous Devonian rocks.

Comments.—The rocks here referred to the Cambrian are the so-called gold-bearing slates. This great series I have regarded as probably equivalent to, and belonging in the same geological province with, slates of Newfoundland unconformably underlying the Cambrian. I have therefore doubtfully referred the Nova Scotia slates to the Algonkian. No palæontological evidence is given in this paper which decides between the Cambrian and Algonkian periods.

Bonney[1] states that the Eozoon of Côte St. Pierre is either a record of an organism, or a very peculiar and exceptional condition of a pyroxene-marble of Laurentian age, which is not a result of contact metamorphism in the ordinary sense of the term.

by L. W. BAILEY, Geol. Sur. of Can., Ann. Rep. for 1892–3 (new series), Report Q., 1895, pp. 21. With map.

[1] The Mode of Occurrence of Eozoon Canadense at Côte St. Pierre, by T. G. BONNEY, Geol. Mag., new ser., Vol. II., 1895, pp. 292–299.

Adams[1] describes a district of 3500 square miles of pre-Cambrian rocks belonging to the Grenville series immediately east of the original Laurentian area, described by Logan and Ells, and northwest of the city of Montreal. A subordinate part of the area about Trembling Mountain and another area to the west of St. Jerome are referred to the fundamental gneiss. The Grenville series occupies the major portion of the district, but about 1000 square miles is occupied by anorthosite, which occurs in one large area known as the Morin area, and ten smaller masses. The Morin anorthosite encloses detached masses of the gneiss. There are also present in the district one mass of intrusive syenite covering an area of thirty-six square miles, and a much larger one of granite in the northeast portion.

The Grenville series is composed of rocks in well-defined bands, the whole exhibiting a clear foliation, usually parallel to the banding. The series thus has a decidedly stratified appearance, similar to that presented by sedimentary rocks. The gneiss which on the west side of the area dips at an angle of 40°, toward the east become nearly flat, often quite so, and these nearly flat gneisses extend to the north and east far beyond the limits of the map. Throughout this area of flat-lying rocks, the gneisses with their interstratified limestones and quartzites are as highly crystalline as in the most highly contorted districts and have evidently undergone an extensive stretching or rolling out, resulting in the tearing apart of the less plastic bands with the flowing of the material of the more plastic bands into the spaces between the separated fragments.

Petrographically the rocks of the district are found to fall into four classes:

1. Anorthosites and granites of igneous origin. All gradations may be seen between the ordinary anorthosite and those in which the whole is granulated so as to resemble in appearance a saccharoidal marble. The whole rock thus moved under pressure like so much dough, its continuity being perfectly maintained. This is Professor Heim's "Umformung ohne Bruch," millions of little cracks taking the place of a few larger ones, and it is by this process that granites and many gneisses and other crystalline rocks when deeply buried under great pressure and probably very hot, move and accommodate themselves to stresses. This, it will be observed, is quite distinct and different from the shearing accompanied by the development of new materials, which takes place under other conditions and probably nearer the surface.

2. Augen-gneisses, leaf-gneisses, granulites, and foliated anorthosites, genetically connected with the last group, and largely, if not exclusively, of igneous origin also. The structural characteristic of this class is the cataclastic or granulated one, formed by the mechanical breaking down of the web of the rock under movements induced by great pressure, which movements produce in the rock a foliation more or less distinct, according to their intensity.

[1] A Further Contribution to our Knowledge of the Laurentian (Art. VII.), by F. D. ADAMS, Am. Journ. Sci. (3), Vol. L, 1895, pp. 58–69, with Plates I. and II.

3. A series of crystalline limestones and quartzites, together with certain gneisses usually found associated with them. In these rocks the granulated structure is very subordinate or entirely absent. They are characterized by a very extensive recrystallization with the development of new minerals. These minerals have crystallized under the influence of the pressure which granulated the gneisses of the second class, and are not in any marked manner deformed by it. These gneisses also differ from the granites and gneisses of classes 1 and 2 in chemical composition, giving analyses almost identical with those of slates. Moreover, the rocks of this class are very frequently graphitic, and analyses show that the gneisses correspond in chemical composition more closely with slates than with granites.

4. Pyroxene-gneisses, pyroxene-granulites, and allied rocks whose origin is as yet doubtful.

With regard to the Grenville series, from the presence of numerous and heavy beds of limestone and quartzite, their prevalent banded character, the widespread occurrence of graphite, and the fact that the gneisses associated with the limestones and quartzites have the composition of sands and muds and not of igneous rocks, it is concluded that it is extremely probable that this is an altered sedimentary series, which has been deeply buried, invaded by great masses of igneous rocks, and recrystallized. In places the Grenville sediments may have been mingled with the igneous rocks by actual fusion.

Smyth,[1] C. H. Jr., describes the crystalline limestones and associated rocks of the northwestern Adirondack region. The limestones, instead of being in limited patches as in the eastern part of the Adirondacks, are in extended belts many square miles in area. The limestone belt running through the townships of Rossie and Gouverneur has been traced more than twenty miles along the strike, while the average width is perhaps six miles. A narrower belt extends across Fowler into Edwards township. A third belt crosses the townships of Diana and Pitcairn, with an average width of two or three miles. In addition to these belts, numerous scattered patches have been noted in the western Adirondacks.

The limestones are highly crystalline, coarse, light gray or white rocks, containing silicates in separate crystals or segregated in lumps. Among these phlogopite, graphite, pyroxene, and tourmaline are most common. The limestone is usually so massive that it is difficult to ascertain the strike and dip with any accuracy. When observable, the strike is generally northeast and the dip northwest, though exceptions are common. Garnetiferous and micaceous gneisses and pyroxenic and hornblendic gneisses are intimately associated with the limestone. The former are in some cases distinctly inter-

[1] Crystalline Limestones and Associated Rocks of the Northwestern Adirondack Region, by C. H. SMYTH, Jr. Bull. Geol. Soc. of Am., Vol. VI., 1895, pp. 263–284.

bedded with the limestone, while many of the latter have the appearance of interbedded members, and others closely resemble somewhat modified intrusions. Wherever the hornblendic and pyroxenic gneisses appear, they show a great amount of crumpling and crushing, which goes from slight plication to elaborate contortion or to crushing into angular fragments in a paste of limestone, thus producing remarkable breccias. In all of these cases the limestone shows little or no sign of structural change, having the appearance of a plastic mass in which the contained layers could be twisted to any extent. It therefore follows that the massive and undisturbed appearance of the limestone, when free from gneissic layers, does not show that it has not been subjected to intense mechanical strain, as subsequent to this it may have recrystallized.

This limestone series has a marked resemblance to the Grenville series, but because it is difficult to establish such an equivalency, it is suggested that it be called the Oswegachie series. The areas between the belts of limestone are occupied by gneiss, whose origin and relations to the limestone series is doubtful. The limestone series can hardly be regarded as of other than sedimentary origin. In many cases these gneisses adjacent to the limestone closely resemble the interbedded garnetiferous gneisses, and doubtless should be regarded as members of the limestone series. These varieties pass gradually into more nearly massive gneisses of feldspathic aspect, and these are in a number of cases in direct contact with the limestone. A part of these gneisses at least are of igneous origin, as is shown by their contact relations, but whether this explanation is applicable to them all it is impossible to show. Intrusive in the limestone series are granite, diorite, gabbro, and diabase. Their intrusive nature is shown by all the usual phenomena characteristic of such relations.

The gabbro is most variable in its petrographical character. At one place it is in sharp contact with the granite. The relations of the gabbro to the gneiss are difficult to unravel. At Natural Bridge is found the normal gabbro, and in passing toward the red gneiss it appears to grade into it, and the two may be different facies of the same eruptive mass. The contact zones between the limestone and the intrusive gabbro are narrow and sharply defined, and this fact, combined with the great mechanical disturbances of the limestone series, justifies the conclusion that its metamorphism is largely dynamic.

Kemp[1] describes the crystalline limestones, ophicalcites and associated schists of the eastern Adirondacks. Study of the region seems to corroborate the conception of the Adirondack Mountains, as sketched by Van Hise, as a central intrusion of igneous rocks, with a fringing rim of older gneisses, schists, and limestones. A closer approximation would be to regard

[1] Crystalline Limestones, Ophicalcites and Associated Schists of the Eastern Adirondacks, by J. F. KEMP, Bull. Geol. Soc. Am., Vol. VI., 1895, pp. 241–262.

the intrusions as in several more or less parallel ranges, with remnants of the other rocks in the valleys between them and on the flanks is taken as a whole.

The limestones and the associated rocks always occur in depressions, the resistant ridges consisting of the harder gneiss or anorthosite. The former form sections as broad as 1000 feet, in which the limestone strata are, however, less than half, and the true thickness of which is difficult to determine because of the varying dips, schistosity, and possibility of faults. The white limestones are coarsely crystalline, usually graphitic, and often include silicates, from little scales to large bunches. At Keene Center, in the heart of the Adirondacks, is a white limestone and schist belt which contains magnetic iron ore, and is overlain by garnetiferous and pyroxenic schists, or pyroxenic granulite, the relations indicating that the latter is a gneissic rock interbedded with the limestone.

There is no marked break to be detected anywhere between the gneiss and the overlying limestone. Apparently the whole is a continuous series of strata, which are analogous in appearance with those of the Grenville series of Canada. It therefore does not appear certain that in the eastern Adirondack region are any rocks older than this series. The extent and persistence of the limestones and schists gives ground for believing that the series was a set of calcareous sediments and sandstones which have been metamorphosed and intruded by the anorthosites.

Kemp[1] describes the titaniferous iron ores of the Adironacks. These occur in the gabbros. The ores are regarded as segregations from the igneous magma formed during the process of cooling and crystallization.

Kemp and Marsters[2] give the field occurrence and microscopical characters of the trap dikes of the Lake Champlain region. The dikes are found to be bostonites, diabases, camptonites, fourchite, and monchiquite.

Sears[3] gives a description of each of the rocks of Essex county, Massachusetts. These comprise plutonic rocks, volcanic rocks, Archean rocks, and various metamorphosed sedimentary rocks of Palæozoic age.

Emerson[4] gives an outline of the geology of the Green Mountain region in Massachusetts. The Algonkian rocks comprise the Washington gneiss, Tyringham gneiss, East Lee gneiss, Hinsdale limestone, and Hinsdale gneiss.

[1] The Titaniferous Iron Ores of the Adirondacks, by J. F. KEMP, Abstract in Bull. Geol. Soc. Am., Vol. VII., 1895, p. 15.

[2] The Trap Dikes of the Lake Champlain Region, by J. F. KEMP and F. V. MARSTERS, Bull. 107, U. S. G. S. With map. Washington, 1893.

[3] Report on the Geology of Essex County, Massachusetts, to accompany map, by JOHN H. SEARS, Bull. Essex Inst., Vol. XXVI., 1894, pp. 118–139.

[4] Geol. Atlas of the U. S., Hawley Sheet, Preliminary Edition, by B. K. EMERSON. U. S. Geol. Sur. Washington, 1894,

This series is the equivalent of the Stamford gneiss in Hoosac Mountain. The Algonkian rocks consist of firm, coarse gneisses which contain minerals and possess structures not formed in the later rocks; thick beds of coarse and highly crystalline limestones which contain many minerals rarely found in later limestones, as chondrodite, wernerite, dark pyroxene and hornblende; and coarsely crystallized graphite; considerable beds of pyrrhotite, magnetite, and graphite also.

Because of the presence of the heavy beds of limestones, which were probably derived from shells and corals, we may assume that the whole series, except the hornblende-gneiss of East Lee, was of sedimentary origin, but we know nothing of the limits of the sea in which they were spread. These rocks are overlain by the Cambrian Becket gneiss and Cheshire quartzite. As shown by the basal conglomerate at the Dalton Club House, these rocks rest unconformably upon the Algonkian.

Emerson[1] describes the geology of Old Hampshire county in Massachusetts, which includes the present counties of Franklin, Hampshire, and Hampden. On the western border of the Green Mountain area, as it crosses Massachusetts and overlooking the Housatonic Valley, is a series of pre-Cambrian outcrops, which are the oldest rocks of the state and the substratum on which the others rest. They consist of coarse gneisses, especially characterized by blue quartz and allanite, coarse porphyritic structure and stretching; and by great beds of highly crystalline limestone, containing chondrodite, coccolite, titanite, phlogopite and wernerite.

The most important of these limestone beds are the Hoosac, the Hinsdale, and the Tyringham areas The limestone beds connected with the two latter have caused the two most important passes through the range—the Westfield Valley and the East Lee-Farmington Valley.

On the pre-Cambrian rocks rest the Becket conglomerate gneisses of Cambrian age, and above them a great series of sericite schists (the Hoosac schists, Rowe schists, Chester amphibolite and Hawley schists), which are about contemporaneous with the Stockridge limestone of the Housatonic Valley.

Dale[2] discusses the structure of the ridge between the Taconic and Green Mountain ranges in Vermont, and that of Monument Mountain in Great Barrington, Mass. He finds all the strata concerned to be Cambrian or post-Cambrian.

[1] Geology of Old Hampshire County, in Massachusetts, by B. K. EMERSON, Abstract in Bull. Geol. Soc. Am., Vol. VII., 1895, pp. 5-7.

[2] On the Structure of the Ridge between the Taconic and Green Mountain Ranges in Vermont, by T. NELSON DALE, Fourteenth Ann. Rep. U. S. G. S. (for 1892-3), Part II., 1894, pp. 525-549; and, The Structure of Monument Mountain in Great Barrington, Mass., *Ibid.*, p. 551-566.

Collie[1] describes the geology of Conanicut Island, R. I. The oldest rocks are a series of slates of unknown age, into which was intruded a mass of granite, porphyritic in character. This complex was exposed to weathering influences until a bed of débris lay upon its surface. This surface was depressed beneath the sea, and upon it was laid a great series of carboniferous rocks. The complex was, therefore, the Carboniferous shore line. Into the Carboniferous rocks dikes were intruded, and both were folded, metamorphosed, and have in many places become schistose.

Wolff[2] reaches the following conclusions as a result of his detailed study of the Highlands of New Jersey in the vicinity of Hibernia. The rocks are found to consist of distinct bands of gneiss which can be recognized. These layers have once been nearly horizontal, and are folded into an anticlinal dome which has the characteristics of ordinary folds, and has a distinctly recognizable pitch. The rocks of the series have a top and bottom, the latter being at the center of the dome and the top ones at the periphery. One characteristic horizon, a garnet-biotite-graphite-gneiss, must once have existed over a large part of the present area, and the same is probably true of the lower horizons. The foliation, in part at least, is parallel to the bounding planes of the different layers of rocks. The crystallization of the rock occurred during or after the action of the compressing force which folded the rocks and produced pitch but not before, since this structure is inherent in the shape of the minerals as they crystallized. These facts favor the view that the series is a sedimentary one, in which metamorphism and recrystallization took place contemporaneously with the folding and without fusion, and therefore that it is of Algonkian age.

Keith[3] gives the geology of the Catoctin belt. The pre-Cambrian rocks constituting the Blue Ridge core are all of igneous origin. They include quartz-porphyry and andesite, Catoctin schist, and granite. A detailed lithological description is given of each of these rocks and of their alterations. The Catoctin schist and the granite are separated by areas in which the two are intimately intermingled. The Catoctin schist is an altered diabase, and the diabase is believed to be separable into two flows with a time gap between them. An evidence of this is a discordance of structure. The order of the events was probably as follows: (1) Diabase extrusion, (2) granite intrusion, (3) erosion interval, (4) quartz-porphyry and andesite flows, (5) erosion inter-

[1] The Geology of Conanicut Island, R. I., by G. L. COLLIE, Trans. Wis. Acad. Sci., Arts and Letters, Vol. X., 1894–5, pp. 199–230, with Pl. IV.

[2] Geological Structure in the vicinity of Hibernia, N. J., by J. E. WOLFF, Geol. Sur. of N. J., Ann. Rep. for 1893, pp. 359–369, 1895.

[3] The Geology of the Catoctin Belt. by ARTHUR KEITH, Fourteenth Ann. Rep. U. S. G. S. (for 1892–3), Part II., pp. 285–395; and Geol. Atlas of the U. S., Harper's Ferry Folio. U. S. G. S. Washington, 1894.

val (?), (6) diabase flow, and (7) erosion interval. The different lavas have been folded, faulted, and secondary structures have developed within them. Metamorphism was most extensive in the diabase, which has become a well-developed schist. The quartz-porphyry is the least altered.

Merrill[1] describes the disintegration of the granite rocks in the District of Columbia, and finds from chemical analyses, calculated on a water-free basis, that they are very similar to those of the original rocks, and therefore that the rocks are as much disintegrated as decomposed. The chief chemical change is hydration.

Haworth[2] maps and fully describes many areas of pre-Cambrian crystalline rocks of Missouri. These occur in irregular areas and isolated hills extending over an area seventy miles square in the southeastern part of the state. The rocks consist of granites, granophyres, and porphyries, which are occasionally cut by diabase dikes. Some of the granophyres are located between the granite and the porphyry areas, and seem to be a connecting link between them. At other times they are in contact only with the granite or with the porphyry, in which case the connections are traceable in one direction only. It is concluded that all are different facies of a magma belonging to a single period of igneous activity. Associated with the pre-Cambrian are clastic beds occupying small areas, as for example, at the summit of Pilot Knob.

Hill[3] finds in Indian Territory in the heart of the area occupied by the Chickasaw Nation, a granite called the Tishomingo granite, which appears to be of pre-Palæozoic age.

Russell[4] finds as a result of a geological reconnoissance in central Washington that in Okanogan county there are granites, schists, quartzites, and allied rocks. Resting upon the upturned and eroded edges of these crystalline rocks is the Kittitas series, which belongs to the Tertiary system.

Iddings, Weed, and Hague[5] describe and map the geology of the Livington sheet, Montana. Archean crystalline rocks constitute a part of the southern half of the region. These include mica-schists, phyllite, gneiss, and granite. Much of the granite is eruptive and carries angular blocks of other

[1] Disintegration of the Granitic Rocks of the District of Columbia, by GEORGE P. MERRILL, Bull. Geol. Soc. Am., Vol. VI., 1895, pp. 321–332, Pl. XVI.

[2] The Crystalline Rocks of Missouri, by ERASMUS HAWORTH, Missouri Geol. Sur., Vol. VIII., 1895, pp. 84–222 with map and plates.

[3] Notes on a Reconnoissance of the Ouachita Mountain System in Indian Territory, by R. T. HILL, Am. Jour. Sci. (III.) Vol. XLII., 1891, pp. 11–124.

[4] A Geological Reconnoissance in Central Washington, by I. C. RUSSELL, Bull. 108, U. S. G. S., p. 20, with map. Washington, 1893.

[5] Geol. Atlas of the U. S., Livingston, Folio No. 1, by J. P. IDDINGS, WALTER H. WEED, and ARNOLD HAGUE, U. S. Geol. Sur. Washington, 1894.

rocks. The foregoing are cut by veins and dikes of crystalline rocks, both basic and acid. Resting unconformably upon the Archean rocks is the Belt formation, which is supposed to belong to the Algonkian period. This formation is found on the western flank of the Bridger range. The rocks comprise sandstones, conglomerates, slates, and arenaceous limestones. The series is about 2500 feet thick within the area mapped. The Algonkian rocks are overlain conformably by the Cambrian Flathead quartzite.

Eldridge,[1] from a geological reconnoissance in northwest Wyoming, finds that Archean granites, gneisses, and schists of various types form the crest of the Big Horn, Wind River, Absaroka, and Owl-Rattlesnake ranges. In the Wind River and Absaroka ranges the Archean areas are extensive. Resting upon the Archean rocks and in many places deriving material from them, are the rocks of the Cambrian system.

Cross[2] describes and maps the geology of the Pike's Peak sheet. The oldest rocks here found are Algonkian quartzites and allied rocks, which occur as fragments included in the granite. These vary in size from that shown in Wilson park to minor fragments. The Wilson park mass is nearly 4000 feet in thickness, stands on end, and is exposed along the strike for about five miles. Other important masses of quartzite are in Cooper Mountain and Blue Mountain. These masses are cut by minute dikes and are entirely surrounded by granite. Smaller fragments are very numerous. Associated with the quartzites are certain gneisses and schists which almost grade into the quartzites, and probably represent metamorphosed Algonkian strata. Schists also occur, especially in the Cripple Creek district, and these seem to represent earthy metamorphosed Algonkian rocks. Granites and gneissoid granites occupy much the larger part of the Pike's Peak sheet. The more important granites are the coarse-grained Pike's Peak type and a fine-grained granite. The gneissoid granites are but foliated phases of the granites, and between the two there are gradations. All the granites are cut by coarse granitic dikes and veins. The Silurian rocks rest unconformably upon, and derived fragments from, all the previous formations.

Eldridge[3] maps and describes the Crested Butte sheet, Colorado, and finds that on the northwest and southeast corners of the district are Archean areas. These consists mainly of granite and granite-gneiss, with local developments of gneiss and schist.

[1] A Geological Reconnoissance in Northwest Wyoming, by GEORGE H. ELDRIDGE, Bull. 119, U. S. G. S., p. 17, with Geol. Map. Washington, 1894.

[2] Geol. Atlas of the U. S., Pike's Peak Folio, No. 7, by WILLIAM CROSS, U. S. Geol. Sur. Washington, 1894.

[3] Geol. Atlas of the U. S., Anthracite-Crested Butte, Folio No. 9, by GEORGE H. ELDRIDGE, U. S. Geol. Sur. Washington, 1894.

Walcott[1] gives the results of his study of the Algonkian rocks of the Grand Canyon of the Colorado. The following classification of the rocks is adopted :

Cambrian	Tonto	
— — Unconformity — —		
Algonkian	Grand Canyon	Chuar Unkar
——— Great Unconformity ———		
Algonkian (?)	Vishnu.	

The Vishnu at the one point examined, due south of Vishnu's Temple, consists of micaceous schists and quartzites, cut by dikes and veins of granite. The Unkar terrane, 6830 feet thick, consists of limestones, sandstones, conglomerates, and intrusive and extrusive basic rocks of various kinds. The basal conglomerate is formed largely of pebbles derived from the upturned edges of the pre-Unkar strata. The Chuar terrane, 5120 feet thick, consists mainly of shales of various kinds, but contains 285 feet of limestone. Resting unconformably upon the Grand Canyon series is the Tonto Cambrian. Before the deposition of the latter the Grand Canyon series was planed to a base level, and all the strata of the series were truncated.

Midway in the lower portion of the shales and limestones of the Chuar terrane the presence of fauna is shown by a minute discinoid or patelloid shell, a small Lingula-like shell (which may be a species of Hyolithes), and a fragment of what appears to be the pleural lobe of a segment of a trilobite belonging to a genus allied to the genus Olenellus, Olenoides or Paradoxides. There is also a Stromatopora-like form that is probably organic.

The entire Grand Canyon series is placed in the Algonkian period or Proterozoic era. Various possible correlations of the Grand Canyon with other series may be made, but it is evident that until characteristic fossils are found in the various terranes now referred to the Algonkian, it will be impossible to make any correlations that will be more than tentative suggestions.

Sapper,[2] in 1894, describes and maps considerable areas of Azoic formations in Guatemala. The lowest formations are gneiss and the higher formations are m ica-schists and phyllites, associated with which are crystalline limestones, actinolite-schistt, and quartzites. Closely associated with these schistose rocks are ancient eruptive rocks, including granite, diabase, etc. Whether these Azoic formations are pre-Palæozoic or not cannot as yet be asserted.

[1] Algonkian Rocks of the Grand Canyon of the Colorado, by C. D WALCOTT, JOUR. OF GEOL., Vol III., April–May 1895, pp. 312–330, and 14th Ann Rep. U. S. G. S. (for 1892–3), Part II., pp. 487–524.

[2] Grundzüge der physikalischen Geographie von Guatemala, by CARL SAPPER, J. Perthes' Geog. Anst., Ergänzungsheft, Nr. 113, 1894, pp. 59, with 4 maps.

Authors' Abstracts.

Origin of the Iowa Lead and Zinc Deposits. By A. G. Leonard. Am. Geol., Vol. XVI., November 1895.

The deposits occur in the northeastern corner of the state and form part of a larger area embracing the southwest portion of Wisconsin and northwest corner of Illinois. The ore occurs in crevices in the Galena and Trenton limestones, and in Iowa most of it has been taken from the upper fifty feet of the Galena beds.

The minerals were originally deposited as sulphides along with the sediments in certain areas where, borne by currents, they first came in contact with abundant organic life. There is no evidence of general diffusion and subsequent concentration by surface decomposition of rocks as apparently the case in Missouri.

At a later period the Galena beds were raised into folds and east and west fissures formed which becoming channels for underground waters were enlarged into cave-like "openings." In the latter the ores mostly occur.

There is nothing to show that the deposits were formed by hot solutions rising through fissures from great depths. On the other hand there is abundant evidence to prove that to the process of lateral secretion is due the deposition of the ores in the crevices and that they have thus been derived from the limestone whence they have been leached by surface waters. There is reason to believe that the Galena limestone contains lead and zinc diffused through it in small quantities. This theory does not necessitate the derivation of the minerals from the rocks immediately adjacent, but they may have been leached for a considerable distance on either side. Thus the metalliferous contents of the country rock would be sufficient to supply the deposits.

The Gold-Silver Veins of Ophir, California. By W. Lindgren. Fourteenth Ann. Report of the U. S. Geol. Survey, pp. 243–284.

The deposits described are located in the gold belt of the Sierra Nevada near the contact of a *massif* of granodiorite of late Mesozoic

age with older post-Carboniferous, probably also Mesozoic, amphibolite schists. The latter are in places impregnated with slightly auriferous iron pyrites, forming belts or *fahlbands*. The deposits are typical fissure veins forming two systems, one with a west-northwest strike, the other with a northeast strike; all fissures dip southeast or southwest at angles ranging from 20° to 80°. The vein filling is principally quartz, with very little calcite. Native argentiferous gold, with small quantities of auriferous and argentiferous sulphides comprise the ores. The richest ore is usually concentrated in chutes, mostly of elongated form and dipping east on the plane of the vein. In the amphibolite a distinct connection may frequently be noted between the *fahlbands* and the pay chutes on the veins crossing them. Next to the veins the country rock is altered by replacement to a mixture of carbonates, sericite and iron pyrites. This process, to which nearly all deposits of the gold belt are subject, is illustrated by several analyses.

The fissure systems have in all probability been formed simultaneously by a compressive stress acting in a direction parallel to the trend of the Sierra, and the fissuring was attended with considerable horizontal motion. Hot siliceous and carbonated solutions containing heavy metals dissolved in alkaline sulphides ascended the veins, altering the wall rock and depositing the silica and ores in the largely open fissures. Action of percolating surface waters seems out of the question. The auriferous iron pyrites of the *fahlbands* were probably a source of local enriching of the veins, but the derivation of the largest part of the precious metals must as yet be considered an open question. A map of the vein systems accompanies the paper.

Ueber das Norian oder Oberlaurentian von Canada. By FRANK D. ADAMS. *Neues Jahrbuch für Min, etc.*, Beil. Bd. VIII., 1893.

The author having in a former paper shown that the great anorthosite masses supposed by the earlier Canadian geologists to form the upper portion of the Laurentian system, are in reality great igneous intrusions, proceeds in the present article to give an account of a large area of the typical Laurentian to the north of Montreal, in which he deals principally with the petrological character, stratigraphical relation and origin of the Grenville series, which is the true upper portion of the Laurentian. The lower or fundamental gneiss in its uniform character, as well as in its mineralogical and chemical

composition, has the character of an igneous rock. The Grenville series, which appears to rest upon it, frequently has a well-banded character with rapid alternations of various varieties of gneiss, which are in many places interstratified with heavy bands of crystalline limestone, quartzite, etc., has the character of a sedimentary series. A set of analyses of the gneisses, some from the Fundamental gneiss and some from the Grenville series are given, and it is shown that the former have the composition of granite, while the latter have that of sand and clay, a composition quite different from that of any igneous rock, but like that of ordinary sediments. It is also shown that these rocks do not always occur highly inclined, but that over great areas they lie nearly flat or in low undulations, suggestive of thin crust buoyed up by some semi-fluid or plastic material beneath, probably a great batholite granite mass, a portion of which is exposed in one part of the area. The effect of pressure acting after the intrusion of the anorthosites through the Grenville series, is shown in the development of a foliation in the peripheral portion of all the great igneous intrusions, and in the movements which have caused the foliation of the gneiss to follow, and to a certain extent the outline of these more resistant masses. The Grenville series, therefore, comprises certain primeval sediments which have been deeply buried, invaded by great masses of igneous rocks and recrystallized. A map of the area and a photograph of a cliff of the horizontally banded gneiss accompany the paper.

Relations of the Granite and Porphyry Areas in Southeastern Missouri. By CHARLES R. KEYES. Geol. Soc. of Am., Philadelphia, 1895.

As is well known the granitic rocks of Missouri are the only massive crystallines occurring in the Mississippi basin between central Arkansas and Lake Superior and between the Appalachians and the Rocky Mountains. They are, moreover, the most ancient rocks exposed within the limits of the region. As irregular, discontinuous fields they are scattered over a district of about 3000 square miles.

Lithologically the crystalline rocks comprise both acid and basic varieties. The latter, however, are unimportant and occur usually as narrow dikes; the former comprise two well-marked structural phases, one a coarse-grained granite and the other a porphyry. Mineralogic-

ally and chemically the two kinds are practically identical. It is quite manifest that the two phases gradually merge into each other, and the porphyry is to be regarded as the surface facies of the coarse-grained rock.

Heretofore no explanation has been advanced regarding the peculiarities in the geographic distribution of the granitic and porphyritic masses. It is the purpose of the present note to ascribe the surface distribution, as now existing, to certain stages in the physiographic development of the region. In its main features the crystalline district of Missouri is a semi-alpine country. The prominent solitary peaks are irregularly distributed, and form what has been called the St. Francois Mountains. This group of hills constitutes the eastern end of the crest of the Ozark uplift. The extremes of altitude are about 500 and 1800 feet above tide level.

Most prominent among the physiographic features presented are two plains standing at different levels. The first is a deeply incised constructional surface — the Tertiary peneplain; and the second is a moderately dissected plain lying at a lower level — the Farmington lowland. The great Tertiary peneplain forms the general surface of the Ozark uplift. In no part of this raised region, unless it be in the St. Francois district, does any portion of the pre-Tertiary surface project above the broad constructional plain, and even here the nearly uniform height to which the numberless peaks rise would indicate that they also were practically obliterated in Tertiary times, at least as prominent surface features. The Farmington lowland is formed by a broad belt of rather even surface which cuts across the eastern end of the crest. Its general elevation is about 1000 feet above mean tide, a level which is 700 to 800 feet below the horizon of the great peneplain. The lowland is manifestly a plain of denudation. It is the product of a former cycle whose work was interrupted before completion. In point of time this cycle was a later one than that represented by the Tertiary peneplain, and immediately preceded the present one.

In the areal distribution the principal granite field is confined to the northeastern part of the crystalline district and occupies about one-fifth of the entire area. The particular fact to be noted regarding it is that it lies entirely within the lowland plain of denudation. The inference is clear that at this point in the Ozark uplift the porphyritic surface facies of the granite has been removed through erosion in part perhaps in pre-Cambrian times but largely during a more recent period.

The fact that the general surface facies of the acid rock has been actually eroded is shown by several high isolated hills which rise out of the granite area. Some of these, as Knob Lick for instance, are still capped by porphyry. They show further that the granite, to a depth of over 400 feet has been removed in addition to the surface shell of porphyry.

To recapitulate:

1. The granites and porphyries are very closely related genetically, and are to be considered as facies of the same acid magma.

2. Whatever may have been their origin, whether from a few or many points of extravasation, the present relations of the two are that the porphyry is an upper and surface facies of the granite, the thickness of the former being variable, having been originally unequally developed in different places and subsequently modified both ancient and recent erosion.

3. The present geographic distribution of the granites and porphyries is the outcome of very recent changes in the topographic configuration and not of very ancient origin as it has been usually regarded.

4. The existing areal relations of the principal masses of the acid rocks may be traced directly to the systematic and wide-spread physiographic effects arising from recent orogenic action.

5. An element of uncertainty regarding the geological age of the massive crystalline rocks now prevails and an exact determination may always remain a problem yet to be solved.

6. The basal complex of Archæan schists exists in the state within a very moderate distance beneath the highest Palæozoics. It differs widely in lithological characters from the crystallines usually referred to that age, but closely approaches the more typical Archæan rocks of other districts.

Syenite-Gneiss (Leopard Rock) from the Apatite Region of Ottawa County, Canada. By C. H. Gordon. Bull. Geol. Soc. Am., Vol. VII., pp. 95–134. Rochester, December 1895.[1]

In the collections of the Canadian Geological Survey at the World's Fair there were displayed specimens of a rock showing a peculiar

[1] Thesis presented for degree of Doctor of Philosophy, University of Chicago, June 1895.

lumpy aggregation of the feldspathic constituents. During the summer of 1894 the author visited the region from which this rock was obtained and studied its relations in the field, subsequently studying in the laboratory the material obtained.

The rock was found to occur at High Rock, an apatite mine on the west bank of the Du Lievre River about twenty miles above Buckingham, in a series of dikes intersecting quartzites, and pyroxenites. In general the rock has the composition of a syenite though in places carrying more or less quartz, and is often associated with the apatite deposits, but no attempt is here made to show their genetic relationship.

The dike rock in its various phases shows more or less evidence of dynamic action, and the term syenite-gneiss is applied to it. It presents three distinct phases which the author designates as *coarse-grained syenite-gneiss, ellipsoidal syenite-gneiss and streaked syenite-gneiss.* The first consists of a coarse-grained mixture of microcline and monoclinic pyroxene with a small but variable amount of quartz. The rock is divided into irregular blocks by obscure seams which apparently represent recemented cracks. In the second phase it consists of irregularly ellipsoidal or ovoid masses of feldspar and some quartz separated by narrow anastomosing partitions of green interstitial material, chiefly augite. Frequently the crystals of pyroxene, which are elongated in the direction of the prism, lie transverse to the interstitial layer and thus present a more or less pronounced radiate appearance. From the rounded ellipsoidal forms the feldspathic lumps vary to more and more flattened forms until the structure merges into the third phase, in which the pyroxene layers are arranged in parallel bands alternating with somewhat thicker feldspathic layers. Here there is marked diminution in the size of the grains, while quartz becomes relatively more abundant. Large crystals of apatite appear in places inclosed in the ellipsoidal rock, and having the ellipsoids arranged concentrically about them. Masses of apatite also occur in the streaked rock, crushed to a more or less granular, saccharoidal condition, and around them the streaks of pyroxene curve concentrically.

Under the microscope the coarse-grained rock is found to be composed chiefly of microcline, with a much smaller proportion of augite and a variable but usually small amount of quartz. The rock is intersected in various directions by fine, granular bands, made up of microcline and plagioclase, the latter usually containing small nodular

quartz inclusions. The grains of augite sometimes show the effects of mechanical movements in the fracturing of grains which lie in contact with the granular bands.

In the ellipsoidal rock the granular bands are more pronounced and strongly marked by the presence of pyroxene. Quartz appears in greater amount than in the coarsed-grained rock. In the streaked gneiss all the constituents are finer grained. Hornblende appears here frequently, sometimes in sharply idiomorphic crystals. Both in their field relation and in their microscopical structure these rocks show a gradation from the coarsely crystallized rock to the fine-grained streaked gneiss.

In the classification of gneisses it is suggested that the term gneiss be used in the broader structural sense following the prevailing usage among Canadian geologists; where the origin of the rock is known a corresponding qualifying term may be used as diorite-gneiss. Where the origin is unknown, the ending "ic" may be given to the qualifying term to show its structural relations, as dioritic-gneiss. In harmony with this view the rock under consideration would be a pyroxene-syenite-gneiss. As to the origin of the ellipsoidal structure the evidence, while in many respects incomplete, involving as it does much that is as yet little understood in the metamorphism of rocks, seems on the whole to favor the hypothesis of dynamic metamorphism.

Briefly summarized this supposes:

1. That the structure characterizing the Leopard rock is due to orographic agencies and represents an intermediate stage in the development of a streaked augite-syenite-gneiss out of an augite-syenite, which was distinguished by a coarsely crystallized structure and by a somewhat irregular aggregation of pyroxene.

2. That the distribution of the pyroxene has been effected by the solution of portions of the original constituents and their recrystallization along lines marking the location of the cracks.

3. That with continued pressure these lumps have been more and more drawn out, the process being accompanied by recrystallization until the rock assumed the streaked gneissoid form.

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THE

JOURNAL OF GEOLOGY

MAY-JUNE, 1896.

CLASSIFICATION OF MARINE TRIAS.

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INTRODUCTION.

THE Triassic system took its name from the peculiar threefold development in the Germanic basin, in which at the base are beds of sandstone, in the middle are massive and shaly limestones, and at the top, clay shales and thin beds of quartzite. This basin was an interior sea, wholly cut off from the outside world during the greater part of its existence; but its sediments are so accessible to students of European stratigraphy that its local names have been used to designate subdivisions of the Trias all over the world. And ever since the extension of local names became customary, geologists have been sorely puzzled to know

how to identify the pelagic equivalents of Buntsandstone, Muschelkalk and Keuper, since those inland deposits never contain any of the open-sea species.

Instead of being the type of the Trias, the Germanic basin sediments are the exception, and the type is to be sought in strata that were laid down along the borders of open seas. These have long been known in the limestones and shales of the Alps, Himalayas, Salt Range, Siberia, and western America, but the nomenclature has always been obscured by local names without meaning except to the man that gave them. There is, therefore, an urgent need for some uniform system of nomenclature by which Triassic open-sea sediments may be correlated directly with each other, without reference to the old and unrecognizable divisions.

Quite recently the Vienna geologists, Dr. E. von Mojsisovics, Dr. W. Waagen, and Dr. C. Diener, have attempted to give the desired classification, in a paper entitled: "Entwurf einer Gliederung der pelagischen Sedimente des Trias-Systems,"[1] The authors divide the Triassic pelagic deposits into four series, Scythic, Dinaric, Tirolic, and Bajuvaric; and these again into stages and substages, and further into zones, the latter having usually only a local value. The present paper is based largely on the classification of Mojsisovics, Waagen, and Diener, and is intended to show the relations of American marine strata to those of the European and Asiatic regions; the accompanying correlation table is adapted from that of the same authors, as is also the nomenclature of the subdivisions.

Geography of the Trias. The principal regions where Triassic faunas are known are the Alpine province, the Himalayas and Salt Range, northern Siberia, and western America. The faunas of these countries seem to be so different that they may be taken as representing ancient geographic regions.[2] In Mesozoic times

[1] Sitzungsber. Kais. Akad. Wissenschaften Wien. Math. Nat. Cl. Bd. CIV., Abth. I. December 1895, pp. 1–32.

[2] Mojsisovics, Arktische Triasfaunen, Mém. Acad. Impér. Sci. St. Petersbourg, VII. Ser. Tome 36, No. 5.

a sea stretched through southern Europe, eastward to the Himalayas; this was years ago called by Neumayr the "Central Mediterranean," and Suess[1] has recently proposed for it the name Thetys.

Along the western borders of the Thetys were deposited the Triassic sediments of the Alps, Spain, southern Italy, the Balearic Islands, Sicily, Hungary and the Balkan Peninsula. This region was named by Mojsisovics[2] the Mediterranean Trias province. Most of the faunas of the Trias, from near the base to the top, are represented in this region.

To the east the Thetys spread out to the waters of the Indian region, in which the sediments of the Himalayas and the Salt Range accumulated. The Indian waters joined on the north, east, and south with the great Arctic-Pacific Trias ocean, or Arctis of Mojsisovics, along the borders of which were deposited the sediments of northern and eastern Siberia, Spitzbergen, Japan, Rotti, New Zealand, New Caledonia, Peru, and western North America. But in this ocean region there were many provinces as yet unknown, or only vaguely defined.

The provinces themselves, and even the greater geographic regions, were not constant during the entire Trias, for some of the genera show an entirely different distribution during successive epochs. And even where faunas are common to different regions or provinces they do not always occur at the same horizon. Mojsisovics[3] has shown that during the Lower Trias, or Scythic series, the Mediterranean province was cut off from the Indian and the Arctic-Pacific waters, since it had elements that were lacking in those regions, as *Tirolitinæ*, and lacked many others that were plentiful in the Oriental waters, as *Otoceras*, *Ophiceras*, *Gyronites*, and *Flemingites*. Also many faunal elements that were exceedingly plentiful in the one region were rare in the other. Mojsisovics[4] further noted that during the Dinaric

[1] Nat. Sci. Vol. II. No. 13, March 1893.

[2] Abhand. K. K. Geol. Reichsanstalt Wien, VI Band, II Haelfte, Das Gebirge um Hallstadt, I Abtheil, II Band, p. 811.

[3] Arktische Triasfaunen, pp. 143–155.

[4] *Loc. cit.*

division, or Middle Trias, communication had been opened between the Mediterranean and the Indian regions; thus in the Bosnic substage some faunal elements of the zone of *Ptychites rugifer* are common to both regions. From that time on the Triassic faunas of these two regions show strong resemblances to each other. The connection of the Indian with the Arctic region continued, but was growing less marked.

The writer[1] has demonstrated that the Arctic-Pacific region could hold good only for the Lower Trias, and that during the Upper Trias, Tirolic series, the faunas of California were nearly identical with those of the Himalayan and Alpine provinces, the zone of *Tropites subbullatus* being clearly defined and with nearly identical faunas in all three regions.

Thus in Tirolic time the Arctic-Pacific sea, or Arctis, must have been broken up, and the faunas of the Mediterranean region, or Thetys, must have mingled with those of the great ocean. But that there were other Triassic regions, at present unknown, is seen from the fact that *Tropitidæ* appear suddenly in great numbers and without local ancestors during the Karnic stage of the Upper Trias in both California, India, and the Alpine province. The province where the *Tropitidæ* originated is as yet unknown, but it probably lies outside the Mediterranean, and somewhere within the Arctic-Pacific region.

SUBDIVISIONS OF THE TRIAS.

SCYTHIC SERIES.

Brahmanic stage.—The lowest series of the Trias was named by Waagen and Diener[2] from the region of its most typical development in Asia. It is divided into two stages, the Brahmanic and the Jakutic. The Brahmanic stage is further divided into two substages, an older or Gangetic, and a younger or Gandaric. The Gangetic substage is known only in the Himalayas, where it is represented by the *Otoceras* beds, or zone of *Otoceras woodwardi*, the fauna of which consists chiefly of

[1] JOURNAL GEOL., Vol. II, No. 4, pp. 375–376.

[2] Entwurf einer Gliederung der pelagischen Sedimente des Trias-Systems, p. 8.

CLASSIFICATION OF MARINE TRIASSIC SEDIMENTS

Series	Stage	Substage		Zone Fossil	Mediterranean Region	Oriental Region	Arctic-Pacific Regi'n	American Region
Bajuvaric	Rhaetic		22	*Avicula contorta*	Koessen Beds			
	Juvavic	Sevatic	21	*Sirenites argonautæ*	Juvavic Limestone of Hallstadt	Balia Maden in Asia Minor; *Halorella* beds of the Pamir	*Monotis* beds of Rotti	*Pseudomonotis* beds of Peru
			20	*Pinacoceras metternichi*				
		Alaunic	19	*Cyrtopleurites bicrenatus*				
		Laciacic	18	*Cladiscites ruber*		Himalayan Juvavic limestone		
			17	*Sagenites giebeli*				Hosselkus limestone
Tirolic	Karnic	Tuvalic	16	*Tropites subbullatus*	Sandling beds	Himalayan Karnic limestone	*Daonella* beds of Rotti	with *Subbullatus* and *Trachyceras* faunas
		Julic	15	*Trachyceras aonoides*	Raibl beds			Swearinger slates
		Cordevolic	14	*Trachyceras aon*	St. Cassian beds			
	Noric	Longobardic	13	*Protrachyceras archelaus*	Wengen beds		Nipon beds of Japan	Triassic beds of Queen Charlotte Islands
		Fassanic	12	*Dinarites avisianus*	Marmolata beds			Pitt Shales of Shasta Co., California; Star Peak beds of Nevada
			11	*Protrachyceras curionii*	Buchenstein beds			
Dinaric	Anisic	Bosnic	10	*Ceratites trinodosus*	Upper Muschelkalk	*Ptychites rugifer* beds of the Himalayas	*Daonella* beds; Spitzbergen; Beds of Russkij and Olenek	
		Balatonic	9	*Ceratites binodosus*	Lower Muschelkalk	*Sibirites prahlada* beds of the Himalayas	*Posidonomya* beds	
	Hydaspic		8	*Stephanites superbus*		Upper *Ceratite* limestone of the Salt Range		
Scythic	Jakutic		7	*Flemingites flemingianus*	Zone of *Tirolites cassianus*	*Ceratite* sandstone of the Salt Range; *Subrobustus* beds of the Himalayas	Olenek beds of Siberia	*Meekoceras* beds of Idaho ? Santa Ana limestone of California
			6	*Flemingites radiatus*				
			5	*Ceratites normalis*				
	Brahmanic		4	*Proptychites trilobatus*	Werfen beds of the Tyrolean Alps	*Ceratite* marls of the Salt Range	Beds of Ussuri and Russkij	
		Gandaric	3	*Proptychites lawrencianus*				
			2	*Gyronites frequens*		Lower *Ceratite* limestone of the Salt Range		
		Gangetic	1	*Otoceras woodwardi*		*Otoceras* beds of the Himalayas		

Danubites, *Proptychites*, *Prosphingites*, *Koninckites*, *Flemingites*, *Meekoceras*, *Ophiceras*, *Otoceras*, *and* *Medlicottia*. The two last genera begin in the Permian, but live on into the Trias, *Otoceras* increasing in numbers, and *Medlicottia* becoming scarcer. These beds and their fauna have been described by C. L. Griesbach,[1] and C. Diener.[2] They lie just above the *Productus* shales of the Permian and the sediments grade over gradually from one formation into the other; thus the chasm between the Palæozoic and the Mesozoic is at last bridged over. A complete monograph of this fauna will appear soon in a report by Dr. C. Diener, in Palæontologia Indica, Ser. XV, Vol. II.

The upper or Gandaric substage is represented by marine faunas only in the Salt Range, where it was described by W. Waagen.[3] It comprises the lower Ceratite limestone, and the Ceratite marls. The lower Ceratite limestone is the zone of *Gyronites frequens*, and has a cephalopod fauna consisting of *Dinarites*, *Ambites*, *Proptychites*, *Kymatites*, *Meekoceras*, *Koninckites*, *Lecanites*, *Gyronites*, and *Prionolobus*, all *Leiostraca* but one.

The Ceratite marls comprise two zones, that of *Proptychites lawrencianus* Koninck, and above that of *P. trilobatus* Waagen; their cephalopod fauna consists of *Proptychites*, *Meekoceras*, *Koninckites*, *Gyronites*, *Prionolobus*, *Clypites*, *Ambites*, *Kingites*, and *Danubites*.

The *Proptychites* beds are further represented in the region of the Gulf of Ussuri in eastern Siberia, where they have been described by Dr. C. Diener.[4]

Jakutic stage.—The Jakutic stage is most typically developed in the Salt Range, where it is represented by the Ceratite sandstone, the fauna of which, according to Waagen,[5] consists of

[1] Palæont. Notes on the Lower Trias of the Himalayas, Records Geol. Survey India, XII, 1880, pp. 94–113.

[2] Denkschr. K. Akad. Wiss. Wien. Bd. LXII, 1895, pp. 571 et seq.

[3] Fossils from the Ceratite Formation. Pal. Indica, Salt Range Fossils, Ser. XIII, Vol. II, 1895.

[4] Triadische Cephalopodenfaunen der ostsibirischen Küstenprovinz. Mèm. Com. Gèol. St. Petersbourg, Vol. XIV, No. 3.

[5] Pal. Indica, Ser. XIII, Salt Range Fossils, Vol. II, 1895.

Kymatites, *Kingites*, *Meekoceras*, *Koninckites*, *Gyronites*, *Paranorites*, *Proptychites*, *Flemingites*, *Parakymatites*, *Aspidites*, *Lecanites*, *Prionolobus*, *Dinarites*, *Ceratites*, *Prionites*, *Celtites* and *Acrochordiceras*.

In the Himalayas the Jakutic stage is represented by the *Subrobustus* beds, whose fauna, as listed by Diener,[1] consists of *Ceratites*, *Danubites*, *Hedenstrœmia*, *Meekoceras*, *Lecanites*, *Aspidites*, *Proptychites*, and *Flemingites*, of species nearly related to, and in some cases identical with, forms known in the Salt Range Ceratite sandstone.

This stage is further known in northern Siberia, near the north of the Olenek River; Mojsisovics[2] has described its fauna, which consists of *Dinarites*, *Ceratites*, *Sibirites*, *Meekoceras*, *Hedenstrœmia*, *Kingites*, *Prosphingites*, *Goniodiscus*, *Popanoceras*, *Pleuronautilus*, and *Atractites*. Two of the most characteristic species, *Hedenstrœmia mojsisovicsi* Diener, and *Ceratites subrobustus* Mojsisovics, are common to the Olenek beds of Siberia, the Ceratite sandstone of the Salt Range, and the *Subrobustus* beds of the Himalayas.

In America the Lower Trias, and probably the Jakutic stage, is represented in the *Meekoceras* beds of the Aspen mountains in southeastern Idaho, the cephalopod fauna of which consists of *Meekoceras gracilitatis* White, *M. aplanatum* White, *M. mushbachianum* White, and *Arcestes*[3] sp? These species are somewhat related to forms from the Ceratite sandstone of the Salt Range, and during Jakutic time the western American seas must have been connected with those of India.

In California there are strata that probably belong to the Jakutic stage; in the Santa Ana Mountains, Orange county, Mr. H. W. Fairbanks found in a massive black limestone fossils that probably indicate Lower Trias. They consisted of *Pseudomonotis* aff. *clarai*, a trachyostracan ammonite, and an undetermined brachiopod, probably *Rhynchonella*. *Pseudomonotis clarai* is diagnostic for the Werfen beds, upper part of Lower Trias, in the

[1]Denkschr. K. Akad. Wiss. Wien., Math. Nat. Cl. Bd. LXII, 1895, pp. 571 et seq.

[2]Arktische Triasfaunen.

[3] 12th. An. Rep. U. S. Geol. Surv. Terr. Part 1, pp. 105–118.

Alps, and its near relative may belong to the same horizon in a different geographic province.

In Shasta county, California, the Pitt formation consists of a series of siliceous shales probably in part of Lower Triassic age, but no fossils have yet been found in that part of the series.[1]

Outside the Arctic-Pacific region the Jakutic stage is represented in the Alpine province by the Werfen beds, zone of *Tirolites cassianus;* this fauna has long been taken as the type of marine Lower Trias, until the rich discoveries in India have shown the comparative poverty of the Alpine fauna. In the Mediterranean region are known in this stage only twenty-five *Cephalopoda* against two hundred and twelve in the Asiatic region.

DINARIC SERIES.

Hydaspic stage.—Faunas of the Hydaspic stage are known with certainty only in the upper Ceratite limestone of the Salt Range,[2] where forty-one species have been described, consisting chiefly of *Dinarites*, *Ceratites*, *Prionites*, *Danubites*, *Celtites*, *Acrochordiceras*, *Stephanites*, *Sibirites*, *Goniodiscus*, *Meekoceras*, *Lecanites*. Thirty-five of these species belong to the *Trachyostraca*, and only six to the *Leiostraca*, a marked contrast to the distribution in the Scythic series.

The *Posidonomya* limestone of Spitzbergen may belong here, if one may judge from the stage of development of the ammonites,[3] as may also the limestone of Chitichun in Thibet, according to Dr. Diener.[4]

Anisic stage.—The type of the Anisic stage is found in the Muschelkalk of the Mediterranean region, where it is divided into a lower substage, Balatonic, zone of *Ceratites binodosus*, and on upper, Bosnic, zone of *C. Trinodosus.* These faunas have been described in many works, but all the species have been summed

[1] J. P. Smith, Jour. Geol., Vol. II, No. 6, p. 601.

[2] W. Waagen, Fossils from the Ceratite Formation, Pal. Indica, Ser. XIII, Salt Range Fossils, Vol. II, 1895.

[3] Mojsisovics, Arktische Triasfaunen, p. 152.

[4] Denkschr. K. Akad. Wiss. Wien. Bd. LXII, math. nat. Cl., 1895, p. 596.

up by Mojsisovics in "Die Cephalopoden der Mediterranen Triasprovinz,"[1] and later F. von Hauer has described many species from the Muschelkalk of Bosnia,[2] from which this substage takes its name.

In the Himalayas the Balatonic substage is represented by the zone of *Sibirites prahlada*, and the Bosnic division by the zone of *Ptychites rugifer*. In this horizon there are three species common to the Mediterranean and the Indian regions, *Orthoceras* conf. *campanile* Mojsisovics, *Proarcestes balfouri* Oppel, and *Sturia sansovini* Mojsisovics, and other closely related.[3] Certain beds of the Salt Range also belong here, but their fauna is too poor and too little known to be comparable.

In the Asiatic region the Anisic stage is represented on the shores of the Sea of Marmora;[4] further on the Island of Russkij[5] near Wladiwostoc, Siberia; near the mouth of the Olenek River;[6] also, according to Dr. Diener, near the mouth of the Lena.

The *Posidonomya* limestone and the *Daonella* limestone of Spitzbergen, according to Mojsisovics, represent the Dinaric series, the former probably the Hydaspic, and the latter probably the Anisic stage.

F. B. Meek[7] has described from Star Peak, Nevada, a number of Triassic species, part of which, according to Professor A. Hyatt,[8] belong to the Muschelkalk horizon. Waagen and Diener[9] erroneously make Hyatt cite Muschelkalk from Plumas county, California, but Hyatt's remarks referred only to Nevada. There are, however, in California strata probably of

[1] Abhandl. K. K. Geol. Reichsanstalt Wien. X Band, 1882.

[2] Denksch. K. Akad. Wiss. Wien. Math. Cl. Bd. LIV, 1887, Die Cephalopoden des bosmischen Muschelkalkes von Han-Bulog in Sarajevo; and *ibid*, Bd. LIX, 1892, Beiträge zur Kenntniss der Cephalopoden aus der Trias von Bosnien.

[3] C. Diener, Cephalopoda of the Muschelkalk. Pal. Indica, Ser. XV, Himalayan Fossils, Vol. II, Part 2.

[4] According to the paper by Waagen, Diener and Mojsisovics cited above.

[5] C. Diener, Mém. Com. Geol., St. Petersbourg, Vol. XIV, No. 3.

[6] Mojsisovics, Arktische Triasfaunen.

[7] U. S. Geol. Expl., Fortieth Parallel, Vol. IV.

[8] Bull. Geol. Soc. Am., Vol. III, 1892, p. 400.

[9] Entwurf einer Gliederung der pelagischen Sedimente, etc., p. 26.

Dinaric age. The writer[7] has described a series of shales in

[7] Jour. Geol., Vol. II, No. 6, p. 602.

Shasta county that have the stratigraphic position of the Muschelkalk, and a few species of fossils not incompatible with that age; they are *Trachyceras?* conf. *whitneyi* Gabb, *Pseudomonotis* sp., and *Proarcestes* sp., and some others not identified. The fossiliferous shales lie about 1500 feet below limestones of Karnic ages, with the fauna of the *Subbullatus* zone, and conformably with them.

TIROLIC SERIES.

Noric stage.—For the Upper Trias the Tyrolean Alps have always furnished the types of marine development; the faunas of this series have been compiled and described by Mojsisovics in "Die Cephalopoden der Mediterranen Triasprovinz," and "Das Gebirge um Hallstadt," although the works of von Hauer, Klipstein, Laube, and others have contributed largely to our knowledge of the fossils.

The Noric stage in its typical development is known only in the Alpine region, where it is divided into the Fassanic and the Longobardic substages; but a somewhat different facies occurs also in Japan,[1] although the substages cannot be recognized.

In North America, too, are found strata probably of Noric age, in British Columbia;[2] in Nevada, where part of the Star Peak section belongs to the Noric;[3] in California where its fauna and stratigraphy have been described by various authors.[4] The reference of the western American beds to the Noric horizon is based chiefly on the occurrence in them of several species of *Monotis* and *Halobia* allied to Noric forms and to the identity of several of the American species with those from Japan.

[1] Mojsisovics, Ueber einige Japanische Triasfossilien. Beitr. Palæont. Oesterreich-Ungarns, etc., Bd. VII.

[2] J. F. Whiteaves, Contributions to Canadian Palæontology, Vol. I, Part 2, pp. 127–149.

[3] U S. Geol. Expl. Fortieth Parallel, Vol. IV.

[4] W. M. Gabb, Palæont., Calif., Vol. I.; A. Hyatt, Bull. Geol. Soc. Am., Vol. III., pp. 395–400; J. P. Smith, Jour. Geol., Vol. II., No. 6, pp. 603–606.

Karnic stage.—The Mediterranean region has furnished the type for the Karnic stage, and its fauna has been summed up by Mojsisovics in the two works cited above. In the Alps this stage is divided into a lower or Cordevolic substage, zone of *Trachyceras aon*, represented by the St. Cassian beds; a middle or Julic, zone of *T. anonides*, whose type is the Raibl beds; and an upper or Tuvalic, which is represented by the Sandling beds, the most characteristic fossils of which are *Tropites subbullatus* Hauer, and its near relatives.

Outside the Mediterranean region the Karnic stage is represented in the Himalayas,[1] where characteristic faunas of the Julic and Tuvalic substages occur; probably on the Island of Rotti[2] in the Indian Archipelago; and in California, where its fauna has been described and listed in the same papers that were cited under the Noric stage.

Faunal anomalies.—In the Mediterranean region the lower and middle Karnic substages are characterized by the prevalence of *Trachyceras* and *Protrachyceras* and the absence of *Tropites;* while in the upper Karnic *Trachyceras* and *Protrachyceras* have disappeared, being replaced by *Sirenites;* while *Tropites* and its allies make up a large part of the fauna. This is also true of the Himalayan province, where the *Subbullatus* fauna appears after that of *Trachyceras aon*, and not intermingled with it. In those regions *Trachyceras* does not seem to have left any descendants in upper Karnic time, and *Tropites* and its near allies seem to have no local ancestors, but have migrated in from some region outside the Thetys sea.

In the Karnic beds of California,[3] just at the top of the *Halobia* slates, are found great numbers of *Protrachyceras* and *Sirenites*, associated with *Tropites Subbullatus* Hauer, and numerous other species of *Tropites Bullati*. One of the *Protrachycerata*

[1] C. DIENER, Denksch. K. Akad. Wiss. Wien, math. nat. C. Bd. LXII, 1895.

[2] A. ROTHPLETZ, Perm Trias und Juraformation auf Timor und Rotti, Palæontographica, 39 Band. 1892.

[3] For the stratigraphy of this series see JOURNAL GEOLOGY, Vol. II, No. 6. J. P. SMITH: The Metamorphic Series of Shasta county, California; and Bull. Geol. Soc. Am., Vol. III, A. HYATT, Jura and Trias at Taylorsville.

resembles closely *P. Attila* Mojsisovics, a characteristic form for the middle Karnic, zone of *Trachyceras aon* in the Mediterranean region. The numerous species of *Sirenites* all seem to belong to the group of *Senticosi*, characteristic of middle Karnic; the half dozen or more species of *Paratropites* might belong to either the middle or the upper horizon, as might also the species of *Eutomoceras*. But *Tropites* of the group of *T. Bullati*, and *Sagenites* (*Trachysagenites*), of the group of *S. herbichi* Mojsisovics, are characteristic of upper Karnic. The writer[1] previously called attention to a part of these faunal anomalies, but their full extent was not appreciated at that time.

In the lower part of the Hosselkus limestone of Shasta county, California, there is an undoubted mixture of the middle and upper Karnic faunas. This apparent anomaly might be explained in two ways. Since *Tropites* and its near allies appear as immigrant faunas in the Karnic of the Mediterranean region, the Himalayas and California, it is possible that they may have reached California earlier than they did the other regions, and while the middle Karnic fauna still predominated. Or, on the other hand, it may be that *Protrachyceras* and other members of the *Trachyceras aon* fauna lived on longer in California than in other known regions, so that we have a middle Karnic fauna persisting in upper Karnic time. To the writer it seems more probable that the *Subbullatus* fauna came in earlier, reaching California in middle Karnic time, especially since *Tropites* seems to have been endemic in the Arctic-Pacific region, and since this fauna did not all reach California at the same time, but some came in later. Thus, *Homerites semiglobosus* Hauer, and *Eutomoceras* conf. *quinquepunctatum* Mojsisovics, which in the Alps occur in the zone of *Tropites subbullatus*, in California occur only at a horizon about 150 feet higher, and associated with a fauna that is chiefly different from that of the lower zone. In this higher horizon none of the *Trachyerata* are left, and the cephalopod fauna consists almost entirely of *Tropitidae* and *Arcestidae*, the former being represented by *Eutomoceras*, *Tropites*, *Paratropites*, *Homerites*, and

[1] JOURNAL GEOLOGY, Vol. III, No. 4, p. 494.

Juvavites. These beds may represent the Tuvalic substage, from the prevalence of *Juvavites* of Tuvalic type, although the zone fossil, *Tropites subbullatus* was not found in this horizon. They may, on the other hand, represent the base of the Juvavic stage, since Professor Hyatt[1] cites from Hosselkus limestone of Plumas county *Rhabdoceras* and *Halorites*, neither of which is known below the Juvavic stage in the Alpine region. It may be, however, that here again we have an immigrant fauna reaching this region earlier than other known regions.

BAJUVARIC SERIES.

The Bajuvaric series is typically developed in the Tyrolean Alps, where it is divided into the Juvavic and Rhætic stages. The fauna of the Juvavic stage has been described by Mojsisovics in "Das Gebirge um Hallstadt," and that of the Rhætic by various authors.

Juvavic faunas have further been described from Asia Minor, Pamir, Afghanistan, the Himalayas, New Caledonia, and Peru.[2] In California the upper part of the Hosselkus limestone may belong to the Juvavic stage, as has already been stated in this paper, since *Rhabdoceras* and *Halorites* occur in it.

The Rhætic is so little known in its marine facies that all attempts to refer foreign marine strata to this horizon have failed. The cephalopod faunas of Rhætic age thus far known are very meager, and there is no way of comparing distant localities with each other.

CONCLUSION.

It can no longer be said that the Alps furnish the typical region even for marine Trias; each region of the earth seems to have some open-sea development of a stage that is lacking elsewhere, and new explorations bring to light each year faunas that were unknown before. Each new discovery holds out to us the

[1] Bull. Geol. Soc. Am. Vol. III, Jura and Trias at Taylorsville.

[2] For the literature of the Juvavic stage see Mojsisovics, Denksch. K. Akad. Wiss Wien. Bd. CIV, Abth. I, p. 30, 31.

possibility of tracing migrations of faunas from one region to another, and thus following their development under new conditions. Thus the necessity of combining studies in faunal geography with those in phylogeny, is self-evident.

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THE GEOLOGY OF THE LITTLE ROCKY MOUNTAINS.[1]

The Little Rocky Mountains resemble a wooded island, rising 2000 to 3000 feet above the treeless plains of central Montana, far from the Rocky Mountain Cordillera, whose nearest foothills lie 180 miles to the west. They form a conspicuous geographic feature of a region which is generally destitute of any prominences or land marks for the traveler, and hence are appropriately called by the Indians "Eah héa weetan" or the Island Mountains. They are situated north of the Missouri, between that stream and the Milk River, sixty miles south of the international boundary line. The mountains are formed by a dome-shaped uplift exposing Archæan and Palæozoic rocks, in a region of nearly horizontal Cretaceous strata. Occurring in this isolated position the uplift is of special interest, as its simplicity of structure and distance from the complicated disturbances of the Cordilleran zone make the problem a peculiarly clear one; while the occurrences of the older sedimentary strata and the relations and nature of the igneous rocks are of unusual interest, constituting a needed factor for the discussion of some of the broader problems of general geology.

As the mountains have never been mapped, the accompanying sketch showing the drainage and relief of the region, has been drawn from a few field notes, the crest line being taken from the plat of the survey of the boundary line of the Indian reservation. The altitudes of the main peaks are approximate, but the map will be found useful in locating the various points mentioned in this paper.

[1] Published by permission of the Director of the U. S. Geological Survey.

The present paper is based upon notes made during a brief visit to the region in September 1895, to report upon the mineral resources of the reservation to the Commissioners appointed to treat with the Indian tribes of the Fort Belknap reservation. W. H. Weed.

The only geological observer who has heretofore visited this region is Professor E. S. Dana, who in 1875 made a visit to the southern slopes, east of the debouchure of Rock Creek, noted the occurrences of tilted Carboniferous and Cretaceous rocks,

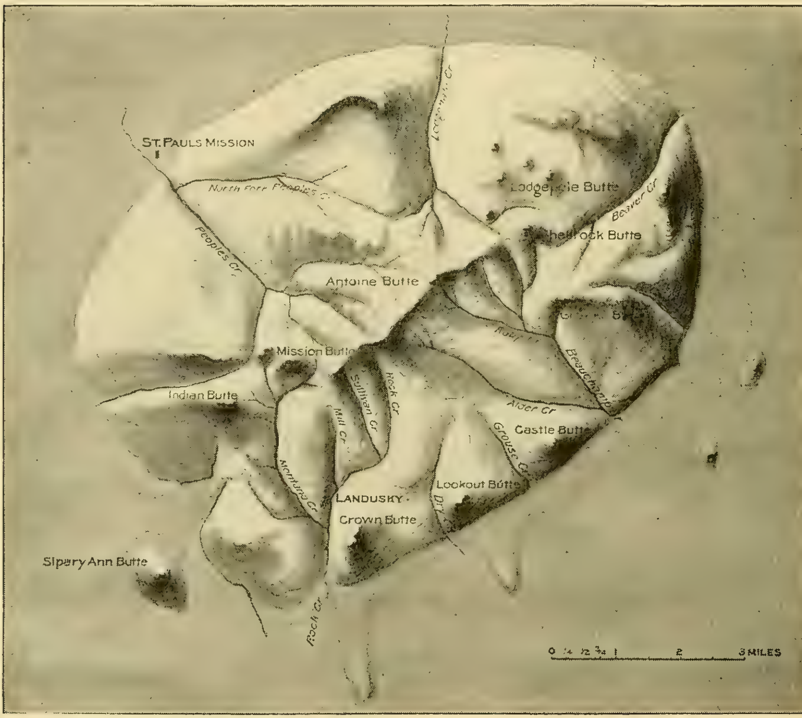

FIG. 1

and described the peculiar porphyry of the laccolithic butte at this point.[1]

In general view, the mountains rise above the plain as a broad and low, dark mountain mass, presenting an undulating crest line with no sharp peaks. A few points do stand apart from the general mass, but when seen from a distance the uplift is a single

[1] Reconnaissance from Carroll, Mont., to the Yellowstone National Park, by Col. William Ludlow, War Dept., Washington, 1876, pp. 127–130.

mountain mass rather than a chain of peaks. Several buttes rising above the slopes of the margin of the uplift form conspicuous features of the region. The highest summit reaches an elevation of over 6500 feet above the sea and about half that height above the surrounding plain. The scenery, though pleasing and attractive, is not grand, as the mountain summits are generally rounded, covered by a thick growth of small pines and are lacking in boldness and the usual striking features of Cordilleran topography. Numerous streams which head within the mountains flow in deep V-shaped gorges that trench the area, but their flowage is small and in summer water is found running only where the channel is cut in schists or porphyry. The scenery of the limestone belt, which forms the outer portion of the mountains, is quite attractive, as the heavily bedded Carboniferous limestones are cut by deep and narrow canyons and the stream valleys present a variety of vegetation that is most pleasing after traveling over the barren, grassy plains.

The only settlement within the region is the town of Landusky, which sprang into existence in the brief weeks of feverish activity consequent upon the discoveries of gold leads in the hills in 1894. The town is built in the upper valley of Rock Creek and contains some twenty or thirty houses and as many more uncompleted buildings stretching along the main street parallel to the stream; it is surrounded by rather open acclivities with scattered pines and grassy slopes, above which occasional limestone crags rise abruptly. A mail road crosses the Indian reservation from Harlem on the main transcontinental line of the Great Northern Railway, to St. Paul's Mission just northwest of the mountains, the road continuing over the mountains to Landusky.

The open plains surrounding the mountains present on the different sides strongly contrasted surface features. To the south extending to the Missouri River, is an open benchland, with long level stretches having a uniform slope of 2° toward the Missouri, and showing good exposures of the soft Cretaceous strata where cut by the streams. The surface has a scanty

covering of well-rounded stream gravel, in part of local origin and in part brought from glacial deposits. It is the type so common throughout the state south of the glacial boundary. North of the mountains the country is covered by the terminal moraine of the two continental glaciers. The surface is a rolling, broadly undulating plain with rounded, flat-topped ridges and low and wide intervening hollows. The larger drift is chiefly Laurentian and is mostly buried, except where washed out by rains or exposed on wind-blown surfaces. Bowlders over two feet in diameter are rarely seen. The quartzite drift of Rocky Mountain origin constitutes the bulk of the material and consists of smooth-surfaced, well-rounded pebbles and small bowlders of red, green, and vari-colored, well-indurated quartzites. Nearing the mountains the terminal moraine becomes more accidented, and there is a gradual ascent to a point a few miles below St. Paul's Mission, where it ends.

Cretaceous beds are seen exposed near the foothills, and steep, grassy, slopes rise up to the white wall of limestone that everywhere encircles the mountains. This limestone wall is perhaps the most prominent feature of the mountain mass when it is seen from a distance, the huge white scollops into which the sharply upturned beds have been cut by erosion being visible for fifty miles from the surrounding plains. Above this limestone wall dark wooded slopes rise abruptly to the rounded summits of the mountains.

Geological structure.—The mountains are formed by a single dome-shaped uplift having a nucleal core of crystalline schists, and involving Palæozoic limestones and the softer overlying Mesozoic beds. This structure has been slightly modified by the intrusion of a great laccolithic body of granite porphyry. The uplift fades out in the minor puckerings of soft Cretaceous beds about the mountain flanks. The strata underlying the surrounding plains are essentially horizontal. This geological structure is shown in the accompanying diagrammatic cross-section of the uplift, Fig. 3, p. 412, which shows the relatively low, broad character of the folding and the relation of the granite

porphyry intrusion to the nucleus of crystalline schists and the overarching sedimentary beds. It is a miniature representation of the geological structure of the Black Hills of Dakota.

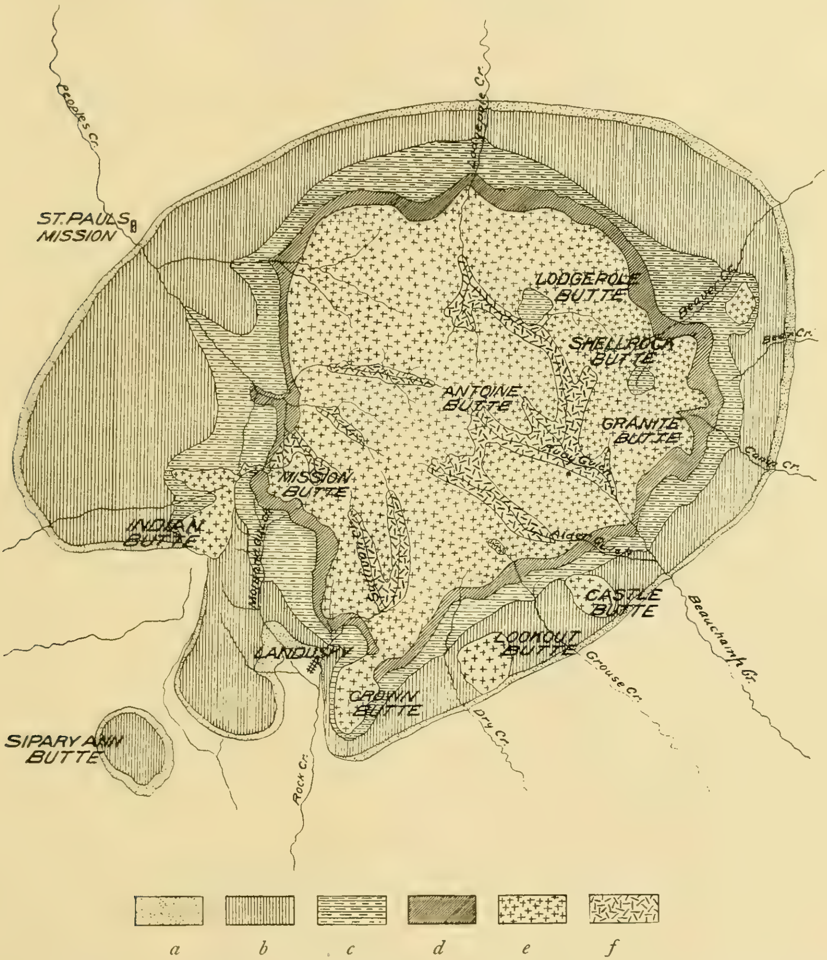

FIG. 2.—a = Jurassic; b = Carboniferous; c = Siluro Devonian; d = Cambrian; e = Porphyry; f = Crystalline Schists.

In the brief time spent in the region no attempt was made to trace out geological boundaries nor to measure detailed sections, it being necessary to ascertain the character and age of

the rocks and the structure of the uplift. The accompanying geological map (Fig. 2) therefore represents merely a sketch of the surface distribution of the various rocks and their general relations to one another, boundaries being drawn without any pretensions to detailed accuracy. The great areal extent of the porphyry is at once seen on the map, and the fact that where the streams have trenched through it the underlying crystalline schists are exposed.

Archæan-Algonkian.—The nucleal core of the mountains is formed of crystalline schists. These rocks are exposed in the headwater gorges of all the larger streams and in the deeply cut saddles of the main crest or ridge of the mountains. The type most usually seen is a black, glistening amphibole schist, or amphibolite, fine-grained, dense, and compact, splitting into flat, bright-surfaced fragments. In the saddle west of Shellrock Mountain the rocks of the series are schistose, occurring in beds but a few feet thick and of rapidly alternating character, showing garnetiferous amphibole and mica schists, pink gneiss with sheared and elongated feldspear crystals, and white quartzites that are clearly altered sandstones. The presence of this latter rock makes it certain that the series is of sedimentary origin, as the original grains are well rounded though now firmly cemented. This would place the rocks in the Algonkian series, but similar schists occurring in Montana have been generally classed as Archæan, and these beds are metamorphosed and quite unlike the slightly altered Belt Mountain Algonkian series.

SEDIMENTARY ROCKS.

The sedimentary rocks form the dominant feature of the region as seen from the surrounding plains. The geological section embraces rocks of the Cambrian epoch, together with a considerable thickness of rocks whose age is not definitely known, occurring beneath limestones carrying characteristic lower Carboniferous fossils. The Mesozoic is represented by Jurassic limestones, and a thickness of several thousand feet of Cretaceous beds, which are found, however, only in the hills

and plains country about the mountains. The following, Table I, shows the general sequence of the sedimentary series. No Lower Cambrian, Upper Carboniferous, or Triassic rocks occur in the region. The oldest unaltered stratified rocks are of Middle Cambrian age. The base of the sedimentary series is a fine, dense quartzite of a pale pink or flesh color, which is sometimes a conglomerate at the base, the pebbles being of clear or slightly turbid quartz. *Scolithus* borings were observed in this bed, but no fossils were found. Overlying this the lowest and oldest of the unaltered sedimentary rocks is a series of shales of greenish or reddish colors, of which no good exposures were found.

TABLE I.

Cretaceous, - -	Sandstones and shales.
Jurassic, - - -	Limestones.
Carboniferous, -	Limestones; massive, very heavily bedded, white rocks. Limestones, laminated, ochreous stained, forming reddish exposures.
Devonian? - -	Limestones; thinly bedded, gray.
Silurian? - -	Limestones; dark gray and black, fetid, mottled beds.
Cambrian, - -	Alternating micaceous shales, impure sandstones, glauconitic limestone, and limestone conglomerate. Shales. Quartzite.
Algonkian or Archæan,	Crystalline schists, gneiss and quartzite.

Fine sections of the limestones are to be seen in almost all of the canyons cut by the mountain streams. The canyon of Peoples Creek, along the channel of which the road from St. Paul's Mission to Landusky has been built, shows especially good exposures of these rocks. The beds dip at 10° down stream and are cut in a narrow gorge. The Cambrian rocks are not well exposed, but have been eroded into a little park or valley between the higher porphyry slopes and the limestone plateau.

Near Landusky the Palæozoic limestones, though prominent features of the landscape, do not present good sections, but the

Cambrian shales are well exposed above the town, and the dark gray, shaly, Jurassic limestones form the foot slopes near the settlement.

Cambrian.—A half mile above Landusky the west bank of Mill Creek shows exposures of 75 to 100 feet of quartzite resting upon the main porphyry mass, which has been intruded between the Cambrian quartzite and the Archæan nucleus of the hills. Above the quartzite are greenish gray shales of which no good exposures were seen, probably 200 feet thick and succeeded by sage-green shales carrying poorly consolidated conglomerates and lenses of glauconitic limestone two inches thick and of varying size. The shale is evidently somewhat calcareous and micaceous, and shows fucoid rolls. The exposure is but 150 feet long, and the shaly series is overlain by thinly bedded limestones. The following section was made at the locality:

No.	Feet	
6	25	Thinly bedded and fissile limestones. Pure limestones with shell remains, alternating with impure, sandy, and more or less conglomeratic beds, the general color being gray.
5	40	Limestone conglomerates and gray shales; greenish sandy layers alternating with purer argillaceous beds. A few thin beds of limestone occur from which a few fossils were taken.
4	50	Green shale beds, carrying limestones and conglomerates.
3	30	Green or copperas-colored shales.
2	300?	Interval in which the beds are not exposed.
1	75	Quartzite, changing to conglomerate near the base; generally flesh colored; mostly brecciated and rusty.

These rocks dip at an angle of 40° toward the town, the strike being N. 60° W. The conglomerates of this section are clearly formed of beach shingle, as the pebbles are all flat. The rocks are very loosely cemented and easily disintegrable, which accounts for the rarity of exposures of these beds throughout the mountains. The impure sandstones interbedded with the shales consist of rounded quartz grains with a green coating or shell of glauconite.

The fossils from the limestones forming part of No. 5 of this

section have been examined by Professor C. D. Walcott, who has identified the following species:

Ptychoparia Owenii Hall.

Obolella nana Meek and Hayden.

Both are Middle Cambrian forms.

Siluro-Devonian rocks.—Above the Cambrian series there are dark-colored, slate-gray and black, fetid limestones possessing the general characteristics of the Silurian and Devonian series as developed in the Rocky Mountain region to the westward. These rocks, however, have not yet been found to contain fossils, and the assumption of their Silurian age is based upon their lithological character and their position between the Cambrian rocks and those of Carboniferous age. The Devonian was not recognized, but in its occurrence westward in the Rocky Mountain province, it is recognizable with difficulty, and the lithological character of the rocks found here indicates that careful search may reveal characteristic fossils of this age.

Carboniferous.—The Carboniferous rocks are well developed and form a series of somewhat thinly bedded limestones at the base, several hundred feet in thickness, which are capped by massive, heavy bedded, structureless limestones which appear to be characteristic of the upper part of the Carboniferous throughout the northern Rocky Mountain region. These are the limestones whose upturned beds form the encircling girdle of the mountains, and in which the picturesque canyons of the streams are cut. Characteristic Carboniferous fossils were observed at a number of exposures. Professor E. S. Dana collected a few fossils from these beds in the canyon east of Rock Creek, identified by Professor Whitfield[1] as follows:

Glauconome sp.?

Productus sp.

Chonetes sp., resembles C.; *granulifera* Owen, also C.; *subumbona* M. and W.

Chonetes sp.

[1] Reconnaissance from Carroll, Mont., to Yellowstone National Park, by COL. WM. LUDLOW, Washington, 1876, p. 129.

Spirifer centronata Winch. "The general expression of these fossils is Lower Carboniferous."

Jurassic.—Overlying the massive, structureless limestones which form the top of the Carboniferous series and are really the most prominent sedimentary rocks of the region, are thinly bedded rocks which generally form somewhat gentle slopes at the base of the steep limestone cliffs, or bedding slopes. These rocks form somewhat detached hillocks of the hogback style, the hillocks being fifty feet high and separated from the limestone slopes by a gentle sag or depression. These beds consist of shaly, gray limestones, carrying Jurassic fossils and changing gradually into impure, marly shales and argillaceous limestones, carrying a fauna of marked Jurassic types. The total thickness is about 100 feet. Good exposures of these beds are found near the town of Landusky, where the road descends from the heights along the slope of Indian Butte. The following fossils collected from these beds have been examined by Mr. T. W. Stanton, who reports the presence of the following species:

Ammonites; fragments of an undecided species.

Belemnites densus M. and H.

Pleuromya subcompressa Meek.

Astarte Meeki Stanton (ms).

Modiola subimbricata Meek.

Gryphæa calceola, var. *nebrascensis* M. and H.

"This is evidently from the Jurassic horizon that is so well represented in the Yellowstone Park and adjacent parts of Montana."

Cretaceous.—The Jurassic rocks are capped by a bed of buff-colored, massive sandstone which weathers red and is six feet in thickness, the rock merging into a variety that breaks down so readily, forming a sandy soil, that no outcrops are seen; its thickness is about twenty feet. This sandstone is capped in turn by a thickness of gray, arenaceous shales. These last beds are in turn capped by sandy shales for at least 300 feet, above which there is a sandstone bed of five to ten feet in thickness, which when exposed forms a long wooded ridge separating the depressions eroded in the soft shales. This sandstone lies at

the base of a series of leaden blue shales, which vary in their character and do not appear to be the "gumbo" shale characteristic of the Pierre beds, so common in the plains country south of the mountain. These shales carry a few fossils and are overlain by other shales carrying sandstone concretions, from which numerous fossils were obtained and which were kindly identified by Mr. Stanton.

Goniobasis sublævis M. and H.

Corbicula cytheriformis M. and H.

Ostrea sp.

This shale series is in turn capped by white, porcellanous beds, in which there are abundant impressions of fish scales. This rock weathers into a sherdy, porcelain-like débris, whose light color attracts attention whenever the rocks are exposed.

IGNEOUS ROCKS.

Distribution.—Igneous rocks cover a considerable part of the Little Rocky Mountain region, forming the central area and occurring in several marginal buttes, the distribution being shown on the accompanying geological map (Fig. 2, p. 403). The rocks are porphyries, belonging to the granite-syenite series, and are of highly alkaline types passing into the phonolites, one rock belonging to the latter family occurring near Landusky.

Occurrence.—The porphyry occurring in the central area of the mountains belongs to a single large body, intruded conformably in the arch of the uplift between the crystalline schists and the Cambrian limestones, the soft shales of the latter formation affording an easy horizon of fracture and intrusion. This is shown in the diagrammatic cross section of the mountains (Fig. 2, p. 403) in which the porphyry is represented as a single intrusive mass, thickened on the summit of the low flat arch and thinner at the edges. This seems to be the actual occurrence in the mountains, though the precise thickness between the limestones and crystalline schists was not measured. This makes the intrusion laccolithic in character.

The cross section shows a thinning of the laccolith to the

east, as actually observed north of Shellrock Butte, with a thickening of the mass beyond. While the observed facts seem to indicate a fairly uniform contact plane between the schists and the base of the porphyry, the upper surface is not so regular, as is shown by the occasional occurrence of areas of limestones as blocks of warped strata at elevations considerably below the highest porphyry peaks. The porphyry intrusions of the marginal summits, such as Crown Butte, Indian Butte, and similar elevations, appear to be small laccolithic bodies of the porphyry breaking through the massive limestones, as is the case at Indian Butte, where the igneous rock occurs in contact with the black shale of the Cretaceous.

If the soft nature of the shales was the determining factor for the intrusion of the porphyry at this horizon, then the parting of the beds by the intrusion would be between quartzite and shale; this is, however, not always the case, for the quartzite at the base of the Palæozoic series is sometimes found beneath the porphyry, between this rock and the crystalline schists, and sometimes above it, and beneath the soft Cambrian shales.

No dikes or ordinary intrusive sheets were observed in the mountains, nor are there any extrusive rocks either here or in the immediate vicinity.

The gulches which cut the porphyry areas are very deep, with steep slopes heavily timbered with pole pine from three to twenty feet high, and the creek bottoms can only be traversed with difficulty. The porphyry is some three or four hundred feet thick upon the principal summits and rests upon black mica schists, into which the streams have cut their gorges, the walls on either side showing typical Archæan exposures capped by great débris slopes of porphyry. The character of the rock formation is readily indicated by the vegetation, as the porphyry exposures and débris slopes are everywhere covered by young pines or, more rarely, form smooth grassy slopes, while the limestone and schist areas are covered by the big-leafed pine, which forms open groves and show occasional rough outcrops of the country rock.

The ridge extending southward from the main divide to the

Alabama mine shows a porphyry, varying slightly from that of the main ridge. Its most noticeable character, however, consists in the prominent white crystals with which it is dotted. The rock shows smooth, slickensided surfaces, and in general crushing and rock movement.

The contact between the porphyry and the Archæan schists was observed on the high ridge east of Antoine Butte. Here there is an exposure of schists some 200 yards across, which shows on the crest of the ridge. The porphyry immediately overlying the schists is somewhat decomposed, and the contact is marked by five feet or so of green clays. The contact has a dip to the south of about 30°.

Parting.—The parting varies in different parts of the mass. At the west base of Mission Butte the porphyry has a platy parting or lamination near the contact with the limestones, and the rock is dense and resists weathering so well that the contact is marked by a wall rising above the adjacent slope of shale and porphyry. At Mission and Granite buttes the rock is a granite porphyry, breaking into massive blocks—the normal jointing of a granular rock. Throughout the mountains generally, however, the porphyry upon weathering breaks into rather small angular fragments, usually but a few inches across, and forms broad slopes of débris covering the mountain sides.

Vent.—The rock body is in the diagram shown extending downward at the side of the arch, but it seems evident that the injection did not take place through the entire circumference of the ring. It becomes, therefore, a matter of interest to locate, if possible, the vent by which the rocks reached the horizon in which they were intruded. The uniform granularity of the rocks observed shows that there is no large stock or core which may be supposed to represent the source of supply. In fact all the indications show that the intrusion is analogous in form to a laccolithic sheet.

South of Mission Butte the slopes back of the Goldbug mine show outcrops of breccias formed of fragments of porphyry with large blocks of quartzite, the latter rock resembling that forming

the basal bed of the Cambrian series. This breccia occurs in rough, craggy masses on the slope immediately above the mine. The crest of the ridge above the mine is formed of a breccia composed of pieces of porphyry in which no quartzite was noticed. At this locality the crest of a lateral ridge north of the mineralized belt is formed of a fairly dense porphyry, which is somewhat brecciated, is mineralized, and generally of a light

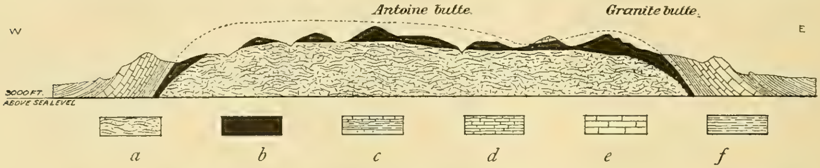

FIG. 3.—a = Crystalline Schists; b = Granite Porphyry; c = Cambrian; d = Siluro-Devonian; e = Carboniferous; f = Mesozoic.

purple or reddish color, the rock carrying about $2.50 in free gold per ton. West of the Goldbug mine the same brecciated porphyry occurs, with the quartzite above it dipping west, and the Cambrian limestones, conglomerates, and shales which occur at this place are somewhat baked and indurated. It is believed that the breccias near this Goldbug property mark the point of eruption of the porphyry magma. This is strengthened by the baking of the sedimentary rocks in contact with this breccia on the west.

Contact metamorphism.—Throughout the Little Rocky Mountains there is but little contact phenomena to be noticed in the sedimentary rocks about the porphyry intrusions. The only place where this action was noticeable is in the vicinity of the Goldbug mine, where the induration and consequent different fracture and weathering of the sedimentary rocks adjacent to the porphyry mass is quite marked, although it is here but a few yards in extent. Elsewhere throughout the mountains no contact metamorphism of any consequence was observed, not even where the intrusive rocks have come in contact with the Cretaceous shales or the massive Carboniferous limestones, as they do in Crown Butte and in the eminence west of Mission Butte.

Petrography.—The main mass of the mountains, including the

central peak, Antoine Butte, is composed of *granite-porphyry*, normally of a gray color and distinguished by large phenocrysts of orthoclase. The rock usually falls apart on weathering into rather small angular blocks, rarely plates which are sometimes a foot in diameter but more often much less, the débris forming extensive slides and talus slopes. A specimen from the main crest near Antoine Butte, typical of the vicinity, is a *granite-syenite-porphyry*. Seen in the hand specimen the rock is compact and dense, of pale lavender-gray color, and shows abundant equidimensional phenocrysts of opaque white feldspar of 1 to 3^{mm} across, thickly scattered throughout the rock. Large crystals of pale flesh-colored glassy orthoclase from 10 to 15^{mm} in length are less abundant, but form the most prominent constituent. The rock is strippled with blackish specks that are probably a decomposed ferro-magnesian mineral. The rock weathers with rusty or reddish-brown stained surface, on which the large orthoclase phenocrysts are very conspicuous.

The section discloses under the microscope an abundance of large phenocrysts of feldspar lying in an extremely fine-grained groundmass composed of quartz and feldspar. Some iron ore is present, dotting the section in very fine, numerous grains. No ferro-magnesian mineral is seen, but very rare small pseudomorphs of muscovite mixed with iron ore show that formerly an extremely small amount of biotite in little tablets was present.

The feldspar phenocrysts are composed of orthoclase and oligoclase. The orthoclase is present in large crystals of the usual type showing the faces *m*(110, *b*(010), and *c*(010), and in habit is stout columnar along the *a* axis. It is twinned at times according to the Carlsbad law and is then thick tabular on *b*(010). A section perpendicular to the obtuse bisectrix gave an extinction angle of about 8° from the cleavage parallel to *c*(001). The crystals of orthoclase are often grouped.

The plagioclase is present in stout tabular crystals, which are usually not so large as those of the orthoclase. There is also less of it in amount. That it is oligoclase is shown by the fact that numerous sections oriented in the zone perpendicular to

b(010) according to Michel Levy's method, and which show both albite and Carlsbad twinning extinguish nearly parallel to the plane of the nicols, the angles for all lamellæ varying but a degree or two. The difference in illumination in the Carlsbad halves for such sections is consequently very small. The total amount of phenocrysts in proportion to groundmass is large.

The groundmass is exceedingly fine-grained, microcrystalline, almost cryptocrystalline in fact; the great difference between the large phenocrysts and the fineness of the groundmass being one of the striking features of the rock. Examined with high powers it is seen to be composed of unstriated feldspar with a subordinate amount of quartz. The feldspar is turbid, apparently from leaves of kaolin. The fineness of grain together with the turbid character, and lack of contact lines between fresh feldspar and quartz prevents the satisfactory determination of the feldspar by Becke's method or other optical means. We can safely conclude, however, from the analysis that plagioclase is not present and that it must consist mainly of orthoclase with some addition of the albite molecule, since the very small amount of lime must be entirely used up in the production of the oligoclase phenocrysts. An analysis by Dr. H. N. Stokes of the United States Geological Survey furnished the following results:

SiO_2	68.65
Al_2O_3	18.31
Fe_2O_3	.56
FeO	.08
MgO	.12
CaO	1.00
Na_2O	4.86
K_2O	4.74
Li_2O	trace
TO_2	.20
MnO	trace
BaO	.13
SrO	.10
H_2O above 110°	.83
H_2O below 110°	.27
Fl	trace
Cl	.03
SO_2	trace
P_2O_5	trace
Total	99.88

The striking feature of this analysis is the exceedingly small

percentage of lime, iron, and magnesia. In spite of the presence of the oligoclase the rock clearly belongs in the alkali series; had more iron and magnesia been present we should expect the lime would have been partly exhausted by the production of augite or hornblende; their absence has forced it into the feldspar. Their absence also explains why with such a comparatively high silica per cent. so little quartz is present; it has nearly all gone into the production of feldspar, of which the orthoclase molecule demands 64.7 per cent., the albite 68.7, while only a very small proportion of the anorthite molecule with $SiO_2=43.2$ is present.

If we neglect the minute amount of potash present in the muscovite and consider all the alkalies and lime as present in the form of feldspar molecules, their molecular proportions

K_2O	503
Na_2O	783
CaO	179

show that they are in round numbers present as follows: Or_{10}, Ab_{15}, and An_2. Since the optical properties of the oligoclase present show it to have approximately the composition Ab_4 An_1 and since albite has not been observed, it is clear that anorthoclase must be present to a considerable extent, in the groundmass.

The lateral ridge at the head of Alder Creek, southeast of Sullivan Butte, is formed of a rock that is slightly different from that of the main ridge, and which being free from quartz, is classed as a *syenite porphyry*. This is cut by zones or leads of decomposed rock, several of which have been prospected. Near the Hawkeye mine where the rock has undergone secular disintegration, the feldspar phenocrysts have occasionally weathered out and form a coarse, sandy débris covering the rock outcrops on the summit of the ridge. The rock is compact, dark, pinkish gray in color, with abundant white phenocrysts of orthoclase which are from 10^{mm} to 20^{mm} across, small phenocrysts of an opaque white feldspar, and small cavities due to the decomposition of some ferro-magnesian mineral are common.

Under the microscope the rock is seen to consist of large

feldspar phenocrysts in a feldspathic finely granular groundmass. Only occasional ferruginous products represent some former ferro-magnesian mineral. The large feldspar phenocrysts are chiefly orthoclase, but there is also a plagioclase present whose optical properties indicate an acid oligoclase. The groundmass in which these lie is composed of unstriated alkali feldspar with quartz practically absent. It is micro-granitoid in structure, with tendency to a broad trachytoid type like those seen in the orthophyres. The rock is considerably altered, the groundmass quite turbid from kaolinization, and the feldspars are also changed though interior cores are still fresh and limpid.

Mission Butte is the sharp, somewhat isolated mountain that is the most prominent point of the western part of the mountains. It is composed of *granite-porphyry* weathering in crags that form a sharp summit that is in strong contrast to the smooth and purple débris slopes and pine covered flanks of the adjacent mountains. The character of this porphyry is somewhat unlike the type prevailing in the mountains. It weathers in rough crags, and breaks in irregular surfaced blocks, in sharp distinction to the fine débris which generally prevails throughout the range. At the west base of the butte where the porphyry is in contact with the sedimentary series, the contact form of the rock resists weathering more effectively than the main body of the porphyry, and forms a wall projecting above the general surface of the ground. In this outcrop the rock is platy, and the lamination is parallel to the contact and to the bedding of the limestone.

The rock, although it differs in weathering and in the appearance of its craggy outcrops from that forming the main mass of the mountains, upon microscopical examination is found to be a facies of the same rock. It is a granite-porphyry with somewhat open structure and miarolitic cavities; has a generally light rusty-gray color, and contains large phenocrysts of glassy orthoclase 10^{mm} to 15^{mm} in diameter, with abundant and less prominent square feldspar crystals of somewhat uniform size, which are 2^{mm} or 3^{mm} across; occasional corroded quartz grains are also

present. The rock is somewhat decomposed, and the cavities are filled with rusty material which produces the yellowish tint of the rock.

The micro-section shows large crystals of feldspar as phenocrysts in a fine-grained groundmass of feldspar, with some quartz. The rock is dotted with fine particles of iron ore and probably a very little biotite was formerly present. The description given of the rock from the main crest, p. 413, will apply perfectly to this rock except that the orthoclase phenocrysts are at times quite large, and on the whole there is less quartz in the fine, microcrystalline, granular groundmass. The feldspar phenocrysts are very fresh, clear, and unaltered, the groundmass rather turbid.

On the north slopes of Mission Butte the underlying schists are exposed beneath the porphyry, the rocks being dark and micaceous. The hilly country lying between Mission Butte and the limestone ridge which forms the northern limit of the mountain mass is devoid of large timber, and the surface appears to be covered entirely by porphyry. A specimen obtained on Peoples Creek, a short distance above the saw-mill, shows a fine-grained rock, breaking readily into large débris blocks which cover the mountain slopes. The rock is of a buff color, but the dark-colored outcrop is so covered by lichens as to closely resemble the quartzites of the Cambrian and deceive the observer. The rock is found just above the Indian's saw-mill, where it occurs near the contact with the sedimentary rocks. It represents a variety not noticed elsewhere in the mountains. It is a compact, dense rock of a decided pinkish buff color, with abundant small phenocrysts of feldspar which are sometimes tabular, and with occasional grains of quartz 1^{mm} across. The rock shows small cavities due to the decomposition of some ferro-magnesian mineral, which on the weathered surface form small pits that are quite conspicuous.

This type is quite similar to that forming Antoine Butte and the central mass of the mountains, except that the phenocrysts are smaller and more thickly crowded. There is also less oligoclase and nearly all of the phenocrysts are of the type of the

orthoclase in the preceding rock. Anorthoclase is probably largely present. The feldspars have been slightly kaolinized—the groundmass, which is similar in character to 920, much more so. No ferro-magnesian mineral was observed save an occasional tiny fiber or shred of ægirine and almost no iron ore; the rock consists almost entirely of alkali feldspars and is practically a sanidinite-porphyry. It belongs clearly in the alkali series.

Shellrock Butte is a round-topped eminence, separated by a deep saddle from Granite Mountain to the east and an equally low divide from the main mountains to the west. The lower slopes are formed of metamorphic schists which show considerable variety, including sheared granite, garnet schists, feldspar schists, and black mica and hornblende schists. The saddle west of this mountain is formed by the head waters of a branch of Lodgepole Creek and of Ruby Creek. The schists extend upward some two or three hundred feet above the saddle. Above this point they are covered by the porphyry débris, which hides the contact and obscures the exact relationship of the two rocks.

Granite Butte is the name applied to the most striking summit and highest elevation of the eastern end of the range. Gentle northerly slopes are in abrupt contrast with a bold craggy summit, abrupt cliffs, and steep rock débris slopes on the south. It is probably the highest point of the mountains, and consists of a granite-porphyry which is somewhat different in appearance from the rock prevailing generally throughout the range. The rock is open in structure and weathers in great blocks that lie piled one upon another like rude masonry.

The rock is a *granite-diorite-porphyry*. It is a somewhat compact rock of a light-gray color, characterized by large crystals of glassy orthoclase which are sometimes 20^{mm} across, and small phenocrysts of opaque white feldspar. Round grains of glassy gray quartz are abundant, and vary in size up to 5^{mm}. The rock also carries stout prisms of chloritized augite, which on the weathered surface have left cavities giving the rock a pitted appearance that is quite noticeable.

In thin section it is seen to be very much the same rock as that forming the central part of the mountains. Large feldspar phenocrysts with fewer ones of quartz in a very fine, quartzose, feldspar groundmass. Only an occasional patch of opacite gives clue to a former ferro-magnesian mineral now resorbed, perhaps biotite.

The large feldspar phenocrysts are mostly of oligoclase or oligoclase-albite, as determined by the method of Michel Levy; they show both albite and Carlsbad twins and are present in thick tabular habits. Orthoclase, though not so prominent, is also largely present. A little sphene was noted. These minerals lie in a fine granular groundmass of micro-granitoid structure, composed of non-striated alkali feldspar and quartz. A few occasional granules of albite were noted in it.

Phonolite.—A rock presenting a marked difference in character from those so far described was obtained from the borders of the porphyry mass, north of Landusky. The rock is the variety of phonolite called *tinguaite* and is found beneath the basal quartzite of the Cambrian, between it and the main mass of porphyry seen on Mill Creek above the town. The rock is a dense, dark-green porphyry, and at the time it was collected was supposed to be a contact form of the main porphyry mass. The same rock was found near the contact between the intruded porphyry mass of Indian Butte and the overlying limestones. A similar rock was found near the Spotted Horse mine in the Judith Mountains, where it also occurred at the contact between the porphyry mass and the altered sedimentary rocks. While definite observations were not made to ascertain if this rock occurs as a dike, yet the fact that it is found in these different localities, and in each case is supposed to be a contact form, seems to negative the idea that it is a dike rock. If, however, this rock does occur as a contact form of the main porphyry mass it is a most interesting occurrence and tends to show a marked differentiation of the main mass toward the cooler periphery. The rock is quite fissile, splitting readily into irregularly surfaced plates, this being due to a parallel arrangement of the tabular feldspar crystals.

It is an aphanitic, very tough, dense and compact rock of a very dark greenish stone color, having a resinous appearance on fresh fracture. Numerous white feldsar phenocrysts, which attain a maximum size of 10^{mm}, occur scattered through the dark groundmass, with rarer small crystals of ægirine-augite in stout black prisms. Prismatic crystals 3 to 4^{mm} in length of a light-brown translucent mineral occur in the rock, but their nature has not been determined for lack of sufficient material.

Occasional small patches of a brown, metallic-lustered mineral are also present, which is shown by its color, by its magnetic properties, and a reaction for sulphur, to be pyrrhotite. The occurrence of this mineral in an extremely fresh and unaltered igneous rock is quite in accord with the rapidly accumulating evidence which different observers are furnishing in regard to the occurrence of metallic sulphides in basic rocks.

In thin section the rock shows large phenocrysts of alkali feldspar and smaller ones of augite in a fine groundmass, of alkali feldspars, ægirite, and nephelite. The large phenocrysts of feldspar are fresh and of sanidine-like character. They are developed very thin tabular on *b* (010) and are usually twinned according to the Carlsbad law. An endeavor to obtain definite data concerning the optical properties of these feldspars was not successful. The augites are stout columnar crystals of ægirine-augite with mantles of ægirine. They do not show any noticeable dispersion of the optic axes. Rarely some rather large crystals of zircon occur.

The groundmass in which these phenocrysts lie is composed of irregular, lath-like, unstriated feldspars arranged in a pronounced trachytoid structure which shows at times a fluidal arrangement. Sometimes the feldspars are in short rectangular forms. They show the patchy, flamed appearance so characteristic of anorthoclase, where the composition varies from place to place between the molecules Ab and Or. No albite twinning is, however, present, but the majority are singly twinned according to the Carlsbad law. Scattered freely through this trachytic groundmass are great quantities of rather short, stout microlites

of ægirite, while between the irregular lath-like feldspars occasional nephelite is seen as a cementing product. The rock powder treated with acid is found to gelatinize readily, thus confirming the presence of the nephelite; the solution in HNO_3 reacts with silver nitrate for chlorine, but gives no reaction with barium chlorides for sulphates, and it is probable that a small amount of sodalite is present but no hauyn or nosean.

The rock is very fresh, an occasional slight kaolinization of the feldspar being the only alteration product seen. From the association with ægirine and nephelite and from the absence of any plagioclase, it is clear that the rock is composed chiefly of anorthoclase with accessory ægirite and nephelite. It thus stands closely related to the Sölvsbergite of Brögger[1] and is an intermediate type between that rock and the nephelite rich tinguaites.

The buttes rising above the mountain slopes near the borders of the uplift are laccolithic bodies of porphyry, whose rocks present slight differences of character from those of the main intrusive mass. The limestone hills at the extreme eastern end of the range and Siprary Anne Butte near Landusky may represent similar laccolithic bodies, in which erosion has not as yet uncovered the eruptive rock.

Crown Butte is the crag-topped mountain which rises abruptly some 600 feet above the town of Landusky. It is composed at the base of massive Carboniferous limestone, which forms an incurved mass between this butte and that near the Goldbug mine.

The laccolithic mass of porphyry forming *Crown Butte* consists of a granite porphyry almost identical with that forming the main mass of the mountains. Seen in the specimen it is a somewhat altered porphyry, showing considerable staining due to oxidation. The rock is generally of a bluish pink color, showing a stony groundmass of a pronounced lavender tint through which are scattered numerous flesh-colored phenocrysts of orthoclase, with minute crystals of altered micaceous material and occasional glassy grains of quartz.

[1] Grorudit-Tinguait Serie, p. 67, Christiania, 1894.

The rock is seen in thin section to be almost exactly like that of the main crest, except that it contains occasional phenocrysts of quartz and the groundmass is of finer grain. It is a typical granite-porphyry with numerous phenocrysts of orthoclase and oligoclase, with occasional partly corroded, resorbed quartzes all of rather large size in an alkali feldspar, quartzose groundmass. This groundmass is excessively fine in grain, almost cryptocrystalline, and the contrast between the size of the phenocrysts and the fineness of the groundmass is even more striking than in that of the main crest.

Indian Butte, west of Landusky, across whose slopes the wagon road has been built, is an extensive body of *syenite-porphyry* breaking through the sedimentary rocks somewhat irregularly. The porphyry is a compact, rather dense rock of a pinkish gray tint, showing numerous small phenocrysts of white feldspar and occasional large crystals of glassy sanidine which are some 10 to 12^{mm} across. The rock is stippled with abundant small black crystals of hornblende, which vary greatly in size and give the rock a general appearance quite different from that prevailing throughout the mountains. No quartz is noticed in the hand specimen.

The thin section under the microscope shows large phenocrysts of orthoclase and smaller ones of oligoclase, with well crystallized prisms of green hornblende imbedded in an extremely fine-granular groundmass of alkali, unstriated feldspar. Apatite, titanite, and iron ore are also present. The oligoclase is often zonally built with layers ranging from acid andesine to oligoclase, this being shown in the optical characters where Carlsbad twins occur. The groundmass is peppered through with excessively minute shreds of a brownish mineral of strong double refraction, which is held to be biotite. The proportion of phenocrysts to groundmass is rather large. The hornblende increases in the depth of its green coloring toward the periphery.

Lookout Butte lies a few miles from Landusky, its porphyry slopes interrupting the white encircling wall of limestone that terminates the mountain slopes on the south. This butte was

ascended by Professor Dana in 1875, who noted its character and height and briefly described[1] the porphyry, the specimens obtained by him being identical with those obtained last summer, as shown by comparison of the hand specimens.

The rock is a syenite-porphyry of very pale-brown, nearly white color. In a groundmass which can be seen by the eye to be very finely granular, there are numerous phenocrysts of orthoclase from one-quarter to one-half inch long, bounded by the usual faces *m* (110), *b* (010), *c* (001), and often *y* (201); they are equidimensional in habit. No ferro-magnesian minerals are seen, but on weathered surfaces the rock has a rusty color due to the oxidation of a small amount of iron ore.

In thin section the rock appears wholly made up of feldspars with a little interstitial quartz. An occasional opacite-like patch shows the existence of a former sparsely scattered iron-bearing mineral which from the shape of the patches and a consideration of the character of the rock seems most likely to have been ægirite. The large feldspar phenocrysts are unstriated; they are quite fresh, sharply bounded, and present several points of interest mentioned beyond. From a consideration of the large amount of albite in the rock it is probable that they are soda-rich orthoclases.

The groundmass of the rock in which the phenocrysts mentioned above are imbedded consists of equidimensional grains of albite, which give short rectangular cuts in the section. The average size of these grains is about one to one-half millimeter in diameter. They show the albite twinning extensively developed and usually in very fine lamellæ; the lamellæ often are interrupted and die out in wedge-shaped strips and then commence again; they appear remarkably like the albites which occur in the Litchfield eleolite-syenite from Maine, and which have been described by Bayley,[2] only that they are not bent or broken. Very rarely the pericline twinning is seen and some-

[1] Op. cit. This is the same rock collected and described by Dana, 1875 (Ludlow report), pp. 128, near top, 129 bottom, and 130 top.

[2] Bull. Geol. Soc. Am., Vol. III, pp. 231 to 252, 1892.

times the Carlsbad. The determination of this feldspar as albite is based upon the facts that in sections in the zone perpendicular to *b* (010) chosen according to Michel Lévy's method, the maximum extinction angle is 16°. One such section gave for one albite twin 16°, for the other 15°, the Carlsbad half, distinguished by the shape of the section, the arrangement of the lamellæ and a very slight but perceptible difference in double refraction in the position of equal illumination, gave extinction angles so nearly similar that the two are practically alike. In convergent light the section shows the exit of a negative bisectrix, but owing to the fineness of the lamellæ the hyperbolas are broken and the image does not permit one to say whether the bisectrix is centered or not. The presence of the quartz and the clearness of its contacts with the albite permit of the use of Becke's method. Both in the parallel and crossed positions the quartz is always found to be the more strongly doubly refracting. All of these determinations point clearly to albite and a quantitative determination of CaO in the rock showed a mere trace of it to be present. The spaces between the albites are filled with quartz, which is at times in solid irregular areas; at other times in little grains; sometimes in micropoikilitic intergrowths with an alkali feldspar. There are also irregular masses of this feldspar present, but they are rare.

The whole character of this rock shows that it is of an alkali type and one in which soda predominates; it bears the same relation to ordinary syenite-porphyry that the Litchfieldite type of eleolite-syenite does to ordinary varieties. This character of the rock impresses itself sharply on the large phenocrysts mentioned above. While with low magnifying powers they show an even unstriated appearance, when examined with high ones it is seen that they are composed of a mingling of two kinds of feldspar substances. They then present between crossed nicols on a gray background an excessively fine spotting of a material which has a somewhat higher double refraction, polarizing in higher tones of white. They recall sheets of iron which have been coated with zinc, or the frosting on a window pane, with a

varied, flamed, or clouded aspect. They are probably similar in some respects to the moiré feldspars described by Brögger. The mingling is of too fine a nature and the particles too minute for the two varieties to be separated and distinguished by optical or chemical means. These fine particles, which are believed to be of albite formed by a secondary breaking up of the soda orthoclase or anorthoclase molecule—are in general oriented similarly with the main feldspar, but not always; in the main, however, the section extinguishes similarly over the whole field. Frequently, also, the phenocryst has a fine outer mantle or skin of the same substance. Scattered through the feldspar phenocryst thus composed, are great quantities of slender laths of albite. They peg the large phenocryst through in every direction and present no regularity of orientation with it, or with one another. They are twinned according to both the Carlsbad and albite laws; often the lath is twinned in halves and as the Carlsbad halves have a nearly simultaneous extinction with the albite twins it is difficult in this case to determine which method is present. That the laths are of albite is shown by optical tests mentioned above, where both twinnings are present, and is to be inferred from the chemical test made for lime. In a few cases the phenocrysts contained these inclusions as short, broad sections oriented in zonal planes. It is believed that these included albites are not secondary, but are of the same age as those in the groundmass, and that their presence shows that the phenocrysts containing them are also of the same age. Thus the phenocrysts spreading outward in their growth would include the albite microlites already formed, but which had not yet developed the stout, thick form, which at present characterizes them in the groundmass.

Summary of petrography.—The study which has been made upon these rocks of the Little Rocky Mountains shows them to belong in the alkali granite-syenite series. The magma which formed them has cooled and crystallized under conditions which gave rise to the granite-porphyry rather than the granular type of structure. On the whole it has been very free from lime, iron,

and magnesia, as shown by the infrequency or absence of minerals containing these elements and by the alkaline nature of the feldspars. There has been, however, a certain amount of differentiation or variation in its character and the resultant rocks grade from true granite-porphyries through quartz syenite-porphyries into syenite-porphyry. In one case, through local increase in lime, they pass into a granite-diorite-porphyry. While the alkaline magma in general is high in silica, a local differentiation, has produced a form rich in alkalies but low in silica, as shown by the tinguaite.

The results then show that petrologically the magmas of the Little Rockies conform to the general type of the detached mountain groups of central Montana in that they are of alkaline, highly differentiated character;[1] they appear to differ in one respect from the general characteristic of this petrographical province in that soda dominates the potash, though but slightly. The occurence of tinguaite adds another locality to the few already known American occurrences of phonolitic rocks. Such rocks have been described from the Black Hills of South Dakota,[2] from Arkansas,[3] from the Trans Pecos district, Texas,[4] from Cripple Creek, Colo.,[5] and from the Bearpaw Mountains of Montana,[6] and specimens have also been received from the Sweet Grass Hills of Montana. Closely related types also occur in the Crazy Mountains of Montana.[7]

Ore deposits.—The ore deposits of the Little Rocky Mountains are of considerable scientific interest, since they represent a type that has thus far been noted at very few localities in this

[1] Highwood Mts. Bull. Geol. Soc. America, Vol. VI, p. 389. 1895. Phonolitic Rocks from Montana, Am. Jour. Sci., Vol. L, 1895. Igneous Rocks of Sweet Grass Hills, Montana, Am. Jour. Sci., Vol. L, 1895.

[2] Pirsson, Am. Jour. Sci., Vol., XLVII, p. 341, 1894.

[3] J. F. Williams, Ig. Rocks Arkansas, pp. 99, 146, 264, 277, 351, 367. 1890.

[4] Osann, Geol. Surv. Texas, Ann. Rep., 1892, p. 130.

[5] Cross, Proc. Colorado Sci. Soc. 1887, p. 167. Pikes Peak Folio, Geol. Atlas, U. S. Geol. Surv. 1894.

[6] Am. Jour. Sci., Vol. L, p. 394.

[7] Wolff and Tarr, Bull. Mus. Comp. Zool., Cambridge, Vol, XVI, 1893, p. 230.

country—a type that is well known because it prevails at the famous Cripple Creek district of Colorado. While the deposits are as yet but little developed, they promise to be actively exploited when the mineral lands which are now within the limits of the Fort Belknap Indian reservation shall be declared open to location. The gold ores are tellurides associated with fluorite, and occur in the altered porphyry. This character of ore, and its association with phonolitic rocks, is of such interest, that it seems appropriate to record here the association of telluride ores with phonolitic rocks which observation shows to prevail not only at the Cripple Creek region but in the Black Hills of Dakota and in the Judith Mountains of Montana.

The mineralized zone, which extends to the vicinity of Indian Peak in a northeast direction across to the north slope of Granite Mountain, is probably about 2000 feet or more in width. Within this area the rock is generally bleached and rotted, white, rusty or pink in color, and cut by veins in which the rock is seamed by quartz stringers and quartz films, and with cavities filled with rusty ore. The pitch of the ore body is steep, some 80° perhaps, and the rock is generally broken by fracture into some angular bits or blocks a foot or so long.

The ores carry gold and occasionally silver. They consist of brecciated or shattered country rock impregnated, coated, and replaced by quartz, often associated with fluorite and carrying small amounts of telluride, pyrite, and possibly other minerals. The ores do not occur in well defined fissure veins with definite mineral walls. The gold occurs both as a telluride and as free gold. In the altered ore forming the surface of the ore deposits and the "float" of the mineral belt, the gold can be seen to be free, but in many cases the gold can only be seen after roasting the ore. A characteristic ore of the district consists of an intimate mixture of quartz and fluorite, whose brilliant purple color makes it readily recognizable.

Superficial alteration of the deposits has caused the oxidation, hydration and leaching of the ore, which consists of a granular, friable, vesicular quartz more or less incoherent and

stained a rusty color by iron. In most of the ore free gold is seen in small spongy masses of a dark coppery color.

The slight amount of development work as yet carried on makes any conjecture as to the mode of occurrence of the ore bodies quite hypothetical. The total absence of dikes, and the fact that no contact deposits have been found, points to the origin of the deposits as due to the alteration of shattered zones of the porphyry itself. That there has been some movement and fracturing of the porphyry since its consolidation is proven by the slickensided surfaces seen near the Alabama mine. The presence of fluorite may have some connection with the telluride ores which are the source of the gold. In the mines of the Judith Mountains the richest ores occur associated with fluorite, and the source of the free gold seems to have been the telluride minerals. This association of fluorite with gold has been noted by various observers at Cripple Creek and in Boulder county, Colorado.[1]

The *Goldbug* mine is the only property which shows any considerable amount of development. It is owned by G. L. Manning and the heirs of Pike Landusky. It was bonded some years ago to the owners of the famous Granite Mountain mine, but was relinquished and is now bonded by another syndicate, who are having the ore body prospected, under the superintendence of M. H. Jacobs, formerly of Hailey, Idaho, whose many courtesies are here gratefully acknowledged. The Goldbug claims are located upon the breccia and shattered porphyry, whose crushed condition permitted the ready passage of mineralizing waters acting upon the feldspathic and basic constituents of the rock, replacing them and filling the seams with quartzose material which is gold bearing.

WALTER HARVEY WEED.

LOUIS V. PIRSSON.

WASHINGTON AND NEW HAVEN,
April 1896.

[1] Mining Geology of the Cripple Creek District, Colorado, by R. A. F. PENROSE, JR., 16th Annual Report of the Director of the U. S. G. S., Vol II, Washington, 1896.

SCHISTOSITY AND SLATY CLEAVAGE.

Some years since I published a paper on the finite, homogeneous strain, flow and rupture of rocks[1] which contained with other matter a new theory of slaty cleavage and the allied less regular schistose cleavage. Colleagues have lately informed me that this paper is too mathematical for their convenience, and I therefore propose to discuss schistosity and cleavage without mathematics. The result cannot be wholly satisfactory in the nature of the case; nevertheless this presentation will suffice for those who care little about the matter and will make my former discussion easier to those who are more interested. No part of that discussion is really difficult, but the chain of reasoning is unavoidably long and therefore trying to the patience. The general idea to be developed is that the deformation of a solid, homogeneous, viscous, isotropic, not infinitely brittle mass will develop structure in it, on not less than one surface nor on more than four surfaces simultaneously. These structure surfaces will in general stand at acute angles to the direction of the pressure to which they are due and the flattening of the strain ellipsoids will not be normal to the pressure except in a limiting case. The assumptions needful to prove these propositions are almost axiomatic, viz., stresses and strains are of the same order of magnitude; a solid mass opposes deformation by forces which are divisible into those independent of the time rate of straining and those which are dependent on this rate.

[1] Geological Soc. of Amer., Vol. IV., 1893, pp. 13–90. An earlier paper, the structure of a portion of the Sierra Nevada of California, appeared in the same series, Vol. II., 1891, p. 49, and a later one, the finite elastic stress strain function, was printed in the Amer Jour. of Science, Vol. XLVI., 1893, p. 337. A paper on the torsional theory of points may be found in Trans. Amer. Inst. Mining Engineers, Vol. XXIV., 1894, p 130. I may mention in the same connection an essay on distributed faults, U. S. Geol. Sur., Monograph III., 1882, chap. iv.

On the other hand experience must be appealed to in the present state of knowledge to decide whether the surfaces of structure will show diminished or increased resistance to splitting.

This theory differs very radically from the older one according to which cleavage occurs only in heterogeneous masses and is normal to the causative force. It is certainly important for geologists to decide between the two, for the effect of geological forces is chiefly manifested in structures of the kind under discussion. In my opinion joints, slickensides, faults, systems of veins, schists and slates are all closely allied manifestations of force and the true theory of one of them must explain them all. These structures constitute the alphabet of the dynamic record. Upheaval and subsidence will never be elucidated until the history of mountain building can be correctly spelled out.

The term "strain" as applied to a solid body signifies a change in shape or size such as would result from the action of external forces.[1] Acquaintance with two strains only is requisite for the purposes of this paper. One of these will be called "pure shear" or simply "shear," and the other will be called "scission."

Pure shear is the simplest conceivable strain. It involves only a change of shape, and this change takes place only in two dimensions. Nevertheless it presents interesting and important properties. If a cube of any solid be subjected to a uniformly distributed load, acting normally as a pressure on two opposite faces, and is at the same time affected by an equal load acting as a normal tension on two opposite faces at right angles to the first pair, as shown in Fig. 1, it will be elongated in one direction and contracted in the other. Such a distribution of forces will not alter the volume; there will be no change of length or direction in lines perpendicular to the plane of the forces; and lines originally parallel to either pair of forces will remain

[1] Stress is force measured per unit area; or in the case of "bodily" forces such as gravity per unit volume. In the mechanics of elastic bodies stresses are either the external forces which cause strain, or the equal and opposite elastic resistances which the external forces excite in the strained mass.

parallel to them however great the distortion may be. If horizontal edges of the unit cube are extended in the ratio α so that these edges in the strained mass have a length α, then the vertical edges are contracted in the ratio $1a$. It is usual to define the quantity α $1a$ as the "amount" of shear. If the

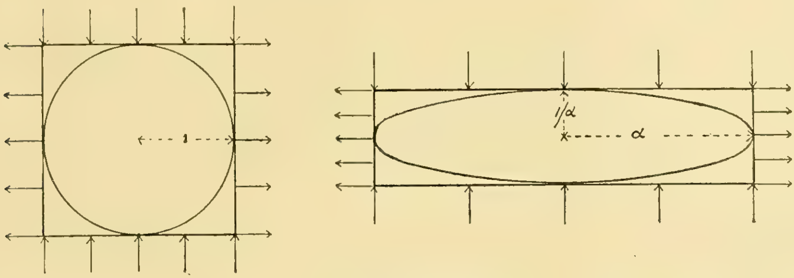

FIG. 1 —Pure Shear.

unstrained cube contained a sphere, this in the strained mass would become an ellipsoid with axes α, 1, $1a$.[1]

Since α is greater than unity, and $1a$ less, there must be radii of the ellipse in the plane of forces which are of unit length, and which are therefore of the same length after strain as they were before. Since the lines perpendicular to the plane of forces are also of unchanged length, it is evident that the circular sections of the ellipsoid pass through the radii of unchanged length in the ellipse. These circular sections of the strain ellipsoid are of as much importance in the theory of deformation as are the corresponding sections of the ellipsoid of elasticity in the theory so familiar to most geologists of the effect of crystals on polarized light.

All planes parallel to the central circular sections are also circular sections. In the plane of any such section there is no distortion when the strain is a simple shear. Any two such

[1] If the equation of the sphere is $x^2+y^2+z^2=1$, and if x_1, y_1 and z_1 are the values which the same points have after strain, $x_1 = \alpha\ x, y_1 = ya$ and $z_1 = z$. Substituting in the equation of the sphere evidently $x_1\ 2a\ ^2 + \alpha^2\ y^2 + z^2 = 1$, represents the sphere after deformation. The volume of this ellipsoid is $\pi\alpha.\ 1.\ 1a =$ which is also the volume of the sphere.

planes are also at the same distance apart after strain as before, for otherwise the volume of the mass must have undergone alteration which would be inconsistent with the definition of pure shear. Since these planes have the same shape, dimensions and distance apart after strain as before it, there is but one change which they can possibly have undergone, viz., a gliding movement past one another. One may regard the entire ellipsoid as intersected by planes parallel to the circular sections and very close together. Consequently also the process involved in a shear consists solely in the sliding past one another of the thin plates bounded by such sections.[1] A convenient model illustrating the nature of shear is a bit of wire netting. If a piece of such netting is pulled diagonally to the mesh, each of the two systems of interwoven wires is distorted much like the traces of the corresponding system of circular sections in the shear ellipse.

The circular sections must necessarily be planes on which the forces are purely tangential; for if the forces had any normal component whatever distortion would ensue. Now it is easy to show that in any shear, however great, the load (or the force per unit area multipled by the area) is exactly the same for every central section passing through the mean axis.[2] In general this load is inclined, so that it has both a component perpendicular to the given section and also a second component tangential to it. On the two axial sections of the ellipsoid, (*i. e.*, the central sections perpendicular to the greatest and least axes) these loads are exactly normal to the surfaces. On the two circular sections the loads are exactly tangential. Since the total load is the same in all cases, the tangential load is evidently a maximum when the load is wholly tangential or when the section considered is the circular section.

It is possible to make geological applications of the theory of pure shear stated above provided that the reader will take for

[1]During the actual process of straining from a sphere to a given shear, even those material planes which are undisturbed at the end of the process undergo distortions, but these deformations are equal and opposite.

[2]This was first shown, I believe, in the paper already referred to, p. 37. I have given a neater proof in Amer. Jour. of Sci., Vol. XLVI., 1893, p. 339.

granted two or three propositions which have been proved elsewhere. It is a fact that a simple uniform pressure acting upon

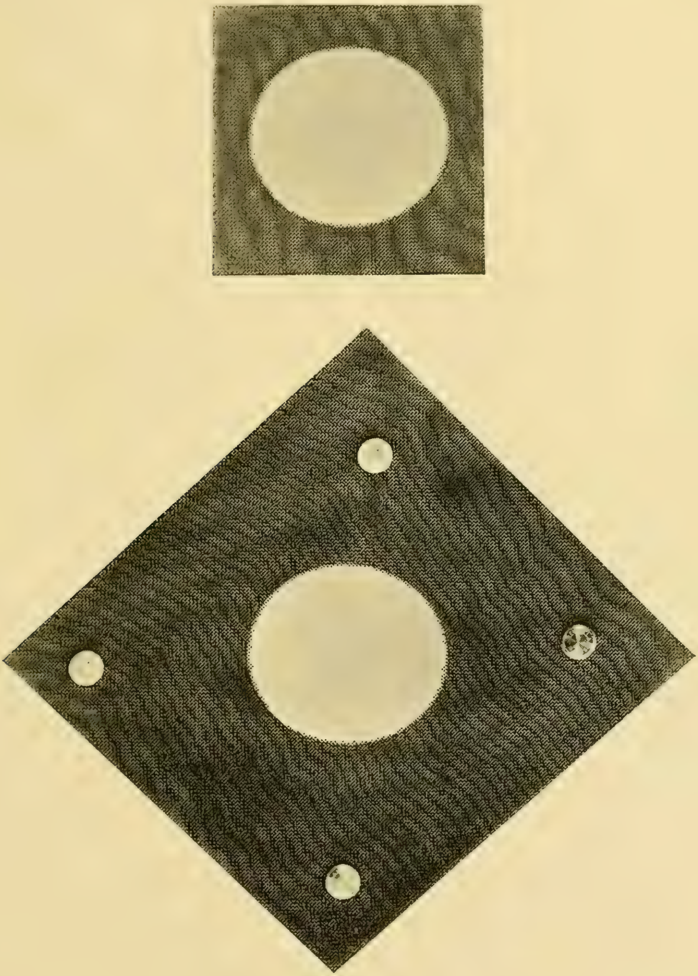

FIG. 2.—Shear illustrated by deformation of a circle drawn on wire netting.

a cube normally to two opposite faces is resoluble into forces which tend to produce[1] a cubical compression and two equal pure

[1] Exactly one-third of the total pressure is employed in producing each of these three elementary strains whether they are of finite or of infinitesimal amount.

shears at right angles to one another. The cubical compression does not tend to produce rupture or distortion, and each of the shears acts independently of the other. Hence in considering the effects of direct pressure upon rock, each shear must be considered by itself, and the effects combined. Were the resolution of forces not what it is, the consideration of pure shear would be almost valueless for geological purposes, because the combination of two exactly equal loads of opposite signs at exactly 90° unaccompanied by other forces must occur in nature only once in an infinite number of times.

If a cube of homogeneous matter is subjected to pure shearing strain it will be deformed gradually until its elastic limit is reached. With most solids analogous to rocks this amount of deformation is very small indeed, so that the shortening of the cube at this limit would not exceed one per cent. and might fall much short of it. For the purposes of this paper the distortion within the elastic limit can be neglected. Just above the elastic limit the mass will begin to undergo permanent deformation. So far as is known every substance whatever is capable of permanent deformation. Were this not true the exceptions to the statement would be perfectly elastic bodies.

The nature of permanent deformation in a pure shear is inferable from what has been stated in preceding paragraphs. It consists in the motion past one another of circular sections of the strain ellipsoid and the motion is such that although the continuity of the mass is not destroyed, relief from pressure does not restore the molecules to their original positions. This irreversible movement of particles along the circular planes of the shear ellipsoid is the simplest case of what Tresca called the *flow* of solids. It differs fundamentally from the flow of liquids, which takes place under corresponding circumstances in a direction perpendicular to the line of force, instead of at an angle somewhat exceeding 45° as is the case with solids. In ordinary solids under pure shearing stress flow begins at almost exactly 45° to the pressure; as the strain increases this angle increases but it can reach 90° only when the thickness of the mass is reduced to zero.

It is very easy to calculate and illustrate the position of the planes of gliding in a pure shear. If the unit cube is reduced by a pure shear to a height $\frac{1}{a}$ (or elongated at a right angle to this direction to a length a) then the tangent of the angle which the circular planes make with the greatest axis of the ellipsoid is $\frac{1}{a}$, which it is worth while to note is also the smallest semi-axis of the ellipsoid. If a differs insensibly from unity, the angle in question differs insensibly from $45°$, and for the values $a = \frac{4}{3}$, 2, 4, the respective corresponding angles are to the nearest degree $37°$, $27°$, $14°$.

By way of illustration, consider a cube of homogeneous matter subjected to pure shear such that its height is ultimately reduced to one-half and let the elastic limit be so small that flow sets in when deformation is very small. Then the first lines to flow will stand at $45°$ (sensibly) to the direction of greatest elongation while at the close of the experiment the last lines to flow will stand at $27°$ to this axis. The material surfaces on which flow first took place of course acquire greater and greater inclination as the deformation increases, but their position is determinable in any state of strain because they connect the diagonal corners of the strained cube.

This case is illustrated in Fig. 3. The broken lines in the distorted cube answer to the directions in which flow begins; the dotted lines are those along which flow takes place at the close of the operation; the short broken or dotted lines in the square representing the undistorted cube show the original positions of the two sets of lines before strain. For strains intermediate between the initial and final states the lines of flow are also intermediate in position.

For comparison with other strains the two wedges in the unstrained cube marked R and r are of much importance. Each of these wedges is bounded upon one side by the line of particles which are the first to undergo flow and on the other side by the last line of particles which undergo flow. In pure shear $R = r$.

One may regard the flow surfaces as mathematical planes (like the plane of the meridian) which occupy different positions relatively to the material particles as the mass undergoes increasing deformation.[1] That set of particles which at any instant coincides in direction with the flow planes undergoes deformation and no other particles are subject to gliding at that instant. The

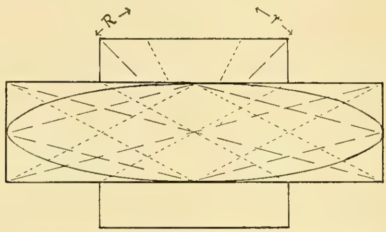

FIG. 3. Flow distribution in pure shear.

flow planes range through successive portions of the material cube and in pure shear they range through equal portions of the cube on each side of the line of pressure. It will be seen later that this is not the case in scission or in any strain into which scission enters as a component. In the illustration the range R or r in the unstrained solid is 18° and the corresponding surfaces in the strained mass make angles of nearly 13°.

The process outlined above must go on in any homogeneous solid substance which is not infinitely brittle when subjected to pure shear under conditions which preclude rupture; whether the mass is of lead or of quartz makes no difference in this respect.

It seems clear that flow in a solid must in some manner affect its resistance to rupture. It is conceivable that a body which had been strained beyond its elastic limit should split with *more* difficulty along the lines of flow or approximately at 45° to the line of force, than in any other direction. Experiment, however, shows that it splits with less difficulty in this direction. The

[1] Whatever the amount of a pure shear may be at any instant, the flow lines are parallel to lines passing through the intersections of the undisturbed cube with the distorted cube.

experimental side of the question will be touched upon later. Flow must cause molecular rearrangement even in chemically stable bodies. One may imagine flow to consist in the rolling over of molecules in alternate very thin layers and the effect being something like the lamellar twinning of feldspars. In such cases it would seem inevitable that the twinning planes should be planes of weakness. The energy of the strain is converted into heat and this heat is developed exclusively along the flow surfaces. In chemically unstable bodies this heat will manifest itself in the production of secondary minerals such as mica, and the new minerals will arrange themselves along the lines of flow. This action appears to me to constitute dynamo-metamorphism so far as such metamorphism attends direct pressure.

Taking it for granted that flow surfaces are surfaces of weakness rather than of increased strength, two distinguishable cases may arise in the progress of shear. It may happen (with some substances and under some relations between the active forces) that, although the direction of greatest tangential load passes away from the direction of initial flow, the diminished tangential load will still produce more motion on the weakened surfaces than in the unweakened but more heavily loaded surfaces. In such cases rupture will ensue at nearly 45°, the distortion will be insensible and the substance is a "brittle" one; or in other words, the difference between the elastic limit and the ultimate strength is exceedingly small. In the opposite case flow will cease on the initial planes and commence anew on the planes where the tangential load has risen to a maximum. Experimentally no absolutely brittle substances are known. There is always so far as known a range of pressure (usually a small one) within which flow occurs along successive surfaces so that considerable deformation without rupture can be affected.

If distortion by pure shear is carried very far without true rupture, the mass will be more or less cleavable in a number of directions separable into two systems. All the cleavages of either system will lie within a few degrees of one another. The consequence will be a somewhat confused foliation. It will be

possible to break out masses with very acute rhombic cross-sections which in the case illustrated in Fig. 3 would have angles of 13°, but such rhombs would themselves be cleavable into still more acute flakes. I should call such a mass a *schist* (whether crystalline or not), reserving the name *slate* for a more regular structure.[1] Sir Archibald Geikie distinguishes slate from schists calling slates "cleaved" and schists "foliated;" he makes approximately parallel lenticular and usually wavy layers or folia characteristic of the schists.[2] This definition seems to answer to my use of the term and to the explanation given above, but many geologists use the terms slate and schist almost interchangeably. In the interest of precision it is most desirable that slate and schist should be distinguished and that geologists should define the sense in which they employ these terms.

Passing now to the second strain to be discussed it will be well to state how scission is produced. The forces acting on any small cubical portion of a strained mass are reducible to three forces which are normal to faces of the cube, and a couple. If the mass is in equilibrium these forces and this couple are exactly balanced by the resistances which the mass itself opposes to strain. The normal forces produce changes of volume and pure shears such as have been discussed above. The effect of the couple is to produce the distortion here called a scission and more usually known as a "simple shear" or a "shearing motion," but never as pure shear. The origin of scission is thus different from that of pure shear. Because it arises from the action of a couple, it is called a rotational strain. Scission is quite as important as pure shear. It may be said to be present in practically all real strains because the absence of scission characterizes only a limiting case which is only approximately realizable even with refined apparatus.[3] Scission is not a strain which by itself

[1] There seems no logic in the constant employment of the term "crystalline" schists unless these are to be distinguished from other schists not crystalline.

[2] Text-book of Geol., 1893, p. 103.

[3] The pole about which the couple tends to produce rotation does not in general coincide with the direction of the maximum, minimum or mean normal stresses. One

is common in nature.[1] When this strain is pushed to the point of rupture it leads to a solitary fault. It is nearly the strain produced when a mass is being cut with shears, and it can be illustrated with a pack of cards. Scission is that strain in which the distance of any particle from two rectangular planes of reference is unchanged, while its distance from a third plane perpendicular to the two others is simply proportional to its distance from one of those others. Thus if x, y, z are the initial coördinates, x_1, y_1, z_1 the final coördinates of a point, and b a constant, $x = x_1, y_1 = y_1, z = z_1 b$ represents a scission. This is illustrated in Fig. 4, where $b = tan\,\theta$. This strain is not attended by a change of volume.

Instead of discussing the nature of rotational strains in general, I shall simply show how to trace a feature of scission which is in fact the effect of rotation. In scission, as in pure shear, the deformation is effected by the gliding of planes answering to the circular sections of the strain ellipsoid; but the range of these two sets of planes through the mass subjected to strain is not the same on each side of the line of pressure. In pure shear the two angles R and r are equal. In scission this is not the case; on the contrary r becomes zero and R gains what r has lost. When the mass has a low limit of elasticity the initial lines of flow will

may either define the couple by the three angles which its pole makes with the principal normal stresses or one may resolve it into three couples with poles coincident with the principal stresses.

The forces at a point are thus defined by six independent quantities, and thes- correspond to six independent resistances which are similar in character to the extere nal forces but not in general similarly oriented. The work done against elastic resistance during a small strain is a homogeneous quadratic function of these six quantities. Such a function contains thirty-six coefficients which reduce to twenty-one by identities. These are the "twenty-one elastic coefficients" of eolotropic matter which are very famous. They have even been celebrated in verse! If the elastic forces between two molecules are reducible to a single force acting between their centers of mass (a theory incorrectly ascribed to Boscovitch) the twenty-one coefficients reduce to fifteen; but this theory is not borne out in general by experiment though some substances, such as glass, closely fulfil its conditions.

Amorphous substances have two elastic constants and regular minerals have only three, but triclinic crystals boast the full number of twenty-one.

[1] Purely tangential force would expand itself close to the surface to which it was applied. Slickensides may be regarded as due to approximately pure scission.

be at sensibly 90° to one another and in scission as illustrated in Fig. 4 one of these directions will be horizontal, the other vertical. When the strain has become great the circular sections of the strain ellipsoid will no longer be at right angles. The angle between them is determinable in terms of the axes of the stress ellipse and (just as in pure shear) it is twice the angle whose

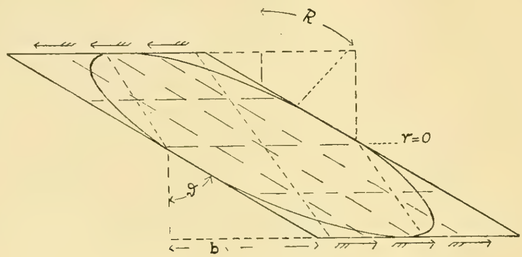

FIG. 4.—Flow distribution in scission.

tangent is the least axis of the ellipsoid. Now since lines parallel to the axis of x undergo no change of length, one of the sets of circular sections must coincide with this direction throughout the strain so that the angle r vanishes. Hence also if one compares a scission with a pure shear in which the ultimate ellipsoids are equal or in which the amounts of distortion are the same, the range of the second set of planes of circular section is just twice as great in scission as it is in pure shear. In dealing with real solids (which always possess viscosity), and finite strains, this difference between pure shear and scission is of great importance; but as scission alone is probably even rarer in nature than pure shear, it will be best to defer comment on this subject until the almost universal combination of pure shear and scission has been discussed.

An inclined force[1] acting on a supported cube would produce among its effects a pure shear and a scission in one plane.[2] It is

[1] The precise direction of a force which would produce a given shear and a given scission is too complex a subject for this paper.

[2] When the mass is homogeneous and symmetrically placed with reference to the forces, the other strains produced would be a second pure shear at right angles to the first and a dilatation. The two pure shears would act independently of one another.

sufficient here to consider as an example a shear and a scission giving equal distortions and simultaneously affecting the same cube. It is very easy to compute all the elements of this strain when for example each strain by itself is such as to increase by one-half the length of the elongated axis. The result is as follows: The length of the major axis would be almost exactly 2;

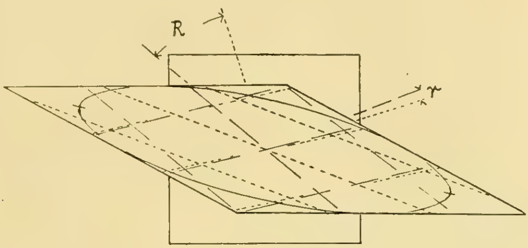

FIG. 5.—Flow distribution when shear and scission of equal amounts are combined.

and it would stand at an angle of $-13°$ to ox. The angle between the final circular sections would be 53°. One of them would stand at $13\frac{1}{2}°$ to ox and the other at $-39\frac{1}{2}°$. The range of the lines of flow referred to the unstrained solid would be $r = 3° \ 27'$, $R = 33° \ 26'$.

In this case one set of planes of maximum tangential load ranges through ten times as great an angle as does the opposite set. To estimate the effects of this difference it is indispensable to consider the influence of viscosity. This subject has its difficulties, but there is nothing to prevent any attentive reader from acquiring the elementary acquaintance with it needful for the present purposes.

The resistances which a mass offers to distortion can be divided into two classes. One of these is independent of the time-rate at which the strain is produced and the other class is not independent of this rate. If both classes are considered it

If one of the shears is of ratio α and the other of ratio β the combination of the two would yield an ellipsoid with axes α, β and $\frac{1}{\alpha}\beta$. The β shear, though independent of the α shear would modify the final angle of the lines of flow due to the α shear by changing the vertical dimensions.

is manifest that all possible resistances are included. The independent class are the elastic resistances. The resistances which depend on the rate of straining are the viscous resistances. Examples of viscous resistance are seen in the rapid subsidence of vibration in a tuning fork. If steel were an ideal elastic solid, a fork in a vacuum would vibrate forever. If rubber were ideally elastic, a band supporting a weight and stretched so as to make the weight dance up and down would continue to stretch and contract indefinitely, while in reality the action ceases in two or three seconds. If a weight is suspended on a wire for a second, the wire may be practically unimpaired by the strain, when the same weight left for a minute would seriously elongate the wire. Flow in such a wire is a process which demands time; and therefore it involves viscosity. Such illustrations show that viscosity is not a merely recondite property of matter which can be relegated to theoretical physicists and neglected by geologists. It is absolutely certain that it must play as important a part in geological deformation as the elastic forces. During an instant of time elastic and viscous resistance are indistinguishable and they coöperate with one another to resist deformation. When one considers a very long period of time instead of a very short one, viscous resistance almost disappears and it vanishes utterly when the time is infinite. It is easy to see that this must be true; for the intensity of resistances which continue to exist after an infinite time is independent of time. Hence, if any mass is strained for a short time its resistance is the sum of its elastic and viscous resistances. If it is strained for a long time, on the other hand, only the elastic resistances will oppose deformation. Again, if a body is strained for a brief period in one direction and for a long period in another, it will act as if it were strong in the former direction and relatively weak in the latter.

In scission the sheets of the mass parallel to the fixed support are constantly impelled to glide over one another by the maximum tangential load and if the forces act for a long time the flow in this direction is opposed only by the elastic resistance. In the other set of planes of maximum tangential load in

a scission this load is at each instant applied to a new set of particles, which offer not only elastic resistance but viscous resistance as well; they are practically and actually stronger for this coöperation. Now suppose that the load has just reached the limit at which flow can take place in the horizontal planes; then this load must necessarily be insufficient to produce flow on the inclined planes. Hence, if flow produces structure at all, such a mass will show structure in one direction and in one direction only.

In the case of combined scission and shear illustrated in Fig. 5, the same principles apply. The fibers forming the wedge *r* are subjected to maximum tangential strain ten times as long as are the corresponding fibers in the wedge *R*. Hence those in the larger wedge offer greater effective resistance to flow than those in the smaller wedge and the pressure might be so adjusted as to render the mass cleavable only in the direction of *r*. The difference between *R* and *r* exists whenever scission forms an element in the strain or whenever there is a couple acting at the point considered.

At first sight this result seems almost too sweeping. It might seem to imply that double structure should be very rare which it certainly is not. This small difficulty is readily explained; for in any substance with a moderately large difference between the elastic limit and the ultimate strength, shear and scission may be so combined that flow without rupture will take place on both sets of planes though faster on one set than on the other. The very rare instances are those in which the two structures are equally well developed indicating pure shear.[1]

In my opinion then true slate, cleavable in directions so nearly parallel that no considerable divergence appears, is due to

[1] The limits of this paper preclude the explanation of a variety of structures arising from minor modifications of dynamic conditions. Flow on one set of planes may be accompanied by sharp joints on the conjugate surfaces. Such are the master joints in slate. When the force is rapidly applied, or when the mass is very brittle or when the lateral support is insufficient, two sets of joints (each with its own spacing) may result. One such set of joints may be suppressed by the action of viscosity.

When deformation in two planes at right angles to one another is considered, two

rotational strains in which scission forms a component. These strains are due to external pressures, always inclined to the normal to the plane of cleavage, and the reason why only one set of cleavages makes its appearance in slate is that viscous resistance in the conceivable second set has prevented flow.

It appears to me possible to avoid this conclusion only by denying either that rocks undergo solid flow or that flow produces cleavage. No geologist will think of denying that rocks flow. The evidences of it are too numerous to be worth mentioning. The mechanical conditions are also well understood. Solid flow without rupture will hardly take place unless there is some lateral obstruction to deformation as well as external pressure. The effect of the lateral confinement is to convert part of the pressure into more cubical compression; consequently the forces producing shears and scissions rise very slowly with increase of external pressure. Under such conditions the deforming stresses may for a long time be kept close to the elastic limit and an infinite amount of flow may be produced in any substance not ideally brittle. The conditions appropriate to flow must be more prevalent at great depths then at small ones, but they cannot be confined to great depths.

That flow really produces cleavage seems to me demonstrated by experiments on solids such as iron. There is evidence that red-hot bar iron or steel is a true solid, and it is known that manufactured bar iron is fibrous and cleavable. This is especially well brought out in experiments on iron plates with high explosives. Even if hot iron were no true solid, the way in which

conjugate systems of cleavages or joints may appear in each, and any one of these four systems may be suppressed by the action of viscosity." One of the shears may fail to act on account of lateral resistance, thus a rock may show 4, 3, 2 or 1 sets of structures due to the same force.

The spacing of fissures is an interesting topic very important in mining districts. My theory is that fissures will so form as to afford the greatest relief by pressure per square foot of rupture. This leads to a definite distribution of faults in homogeneously strained rock.

Tension will not produce joints or cleavages. The theory of the distribution of tension cracks is the explanation of columnar structure.

rail heads are rendered schistose near railway stations by the arrest of moving trains would show the action. In drawing wire similar phenomena appear and in both cases the direction of cleavage is that of flow. Experiments on semi-solids such as pastry and clay are less satisfactory inasmuch as the presence of fluids must disturb the purity of the results, yet in so far as their behavior differs from the known behavior of true fluids, they are instructive. Such experiments when carefully scrutinized yield results compatible with the theory of this paper.

That flow with attendant weakening of cohesion is the origin of slaty cleavage appears to have been recognized by the first investigator to offer a mechanical explanation of this structure. John Phillips in 1843 ascribed cleavage to a "creeping movement among the particles of the rock, the effect of which was to roll them forward." Mr. Daubrée says that schistose or laminated structure is a direct consequence of gliding (glissement), a term which he explains by the remark that the different velocities acquired by contiguous molecules make them glide past one another.[1] Actual cases are on record in which evidences of diminished cohesion (without rupture) make their appearance in rocks in directions parallel to faulted joints. Professor Judd has described such,[2] and they clearly show that flow takes place as a preliminary to jointing and in the less strained portions of jointed rocks.

The deformation of crystals on "gliding planes" which is usually accompanied by secondary twinning is a case of flow in eolotropic masses. The gliding planes also become after relative movement planes of easy cleavage, not in general identical in direction with the inherent cleavage planes of undeformed crystals. The gliding planes in the case of calcite seem to have been known to Huyghens and they have been studied in a great many minerals during the last few decades. Professor Judd has produced gliding planes in quartz by means of pressure, and it is probable that the cleavage which is produced in quartz by alter-

[1] Bull. Soc. Géol. de France, Vol. 4, 1876, p. 541.

[2] Mineralogical Mag., Vol. 7, 1886, p. 81.

nate heating and cooling is due to the flow on such planes.[1] Several mineralogists have also come to the conclusion that the twinning of minerals in nature is largely due to the strain they have undergone. This idea appears to have been suggested in the first instance by Mr. Max Baur in 1878.[2] In massive rocks the minerals are usually strained as a result of cooling and there is much evidence from independent observers[3] that the polysynthetic structures of feldspars and pyroxenes in rocks are wholly or in part due to these strains.

In view of the evidence merely outlined above it appears to me utterly impossible to deny that solid flow does as a matter of fact induce a true cleavage which is parallel to the lines of relative tangential motion or gliding, this cleavage not necessarily being accompanied by any actual ruptures however microscopic. It appears also that this action goes on in thoroughly homogeneous substances such as calcite and quartz. These minerals are not indeed amorphous, but that fact only modifies the direction in which flow will occur most readily, not the principles governing flow. The schistosity of deformed quartz, calcite, feldspar and rock salt crystals cannot possibly depend on the flattening or rotation of included particles.

The theory of slaty cleavage held by most geologists ascribes the structure to the flattening of particles at right angles to the line of pressure and the rotation of mica scales towards the same position. There are some objections to this view. In the first place only the exceptional irrotational strains produce flattening at right angles to the line of force so that, even if fissility were produced by flattening, it would be a mistake to infer that the direction of force was normal to the cleavage.[4] In the second place this theory assumes either that the flattened particles resist fracture more persistently than the matrix in which they are

[1] *Ibid.*, Vol. 8, 1888, p. 1 and Vol. 10, 1892, p. 123.

[2] Zeitsch. der D. Geol. Ges., Vol. 30, 1878, p. 323.

[3] O. Mugge, L. van Werweke, Judd, etc.

[4] In all rotational strains the inclination of the greatest axis of the ellipsoid varies with the amount of strain. It therefore changes during strain when the direction of the force is fixed.

imbedded, or that the flattened particles themselves are cleavable parallel to their greatest extension. If one supposes the material from which slate is made to be a soft mud containing minute sand grains, it seems plausible to assume that in indurated slate also the matrix is weaker than the enclosed particles. But in the analogous dynamo-metamorphosed conglomerates the matrix is often firmer than the pebbles and there is no reason to suppose than this characteristic is not shared by the fine-grained masses. In such cases no cleavage could result from flattening unless the larger grains are cleavable in one direction. This could scarcely happen unless they were mainly mica scales and I do not think that true cleavage would result even in that case. It does not appear to me that any closer approach could be made to slaty cleavage by flattening the particles, even in a weak matrix, than is presented in natural sandstones; for in these also the mica scales and thin particles of quartz are in the great majority of cases parallel to the bedding. Now it is true that two beds of sandstone often split apart from one another with some readiness though the fractured surfaces do not resemble those of slate. This, however, is not in point. If one tries to split a portion of a single, uniform bed of sandstone, it requires careful observation to detect greater facility of cleavage in one direction than another. Thus the mere fact of parallel orientation does not necessarily lead to slaty cleavage.

Tyndall's experiment on wax seems well suited to decide between the old and new theories. It is also one suitable for performance by students.[1] If the flattening theory is correct, compressed cakes should split entirely across, and at least as well at the center as at the edges. If on the contrary I have correctly elucidated the problem there should be a small central core to each compressed cake unaffected by cleavage. For my

[1] In my former discussion, p. 81, I have given some notes on the methods of procedure in this experiment. Tyndall's paper is printed in Phil. Mag., Vol. 12, 1856, p. 37. The horizontal friction between the wax and the rigid surfaces pressing upon it, when combined with the direct pressure, gives an inclined resultant and strains which are rotational excepting along the central vertical line of the wax cake.

part I never could succeed in getting slaty structure at the cores of the fissile mass.

In the interest of geology and of active geologists it is most desirable that a decision as to the origin and nature of slaty cleavage should be reached as soon as possible, and I am in hopes that this sketch of my theory may at least promote discussion of the whole subject. GEORGE F. BECKER.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., January 1896.

Studies for Students.

DEFORMATION OF ROCKS.—III. CLEAVAGE AND FISSILITY.[1]

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Development of fissility in homogeneous rocks.
Development of cleavage and fissility in heterogeneous rocks.
    Development of cleavage in heterogeneous rocks.
    Development of fissility in heterogeneous rocks.
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    Relations of cleavage and fissility to bedding.
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    Relations of cleavage and fissility to thickness of strata.
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DEFINITION OF CLEAVAGE AND FISSILITY.

THE property of cleavage in rocks is here defined as a capacity present in some rocks to break in certain directions more easily than in others. By virtue of this property rock masses may be split into slabs or into leaves. The term cleavage is taken from a property in minerals, and is here confined to a strictly parallel usage. This definition does not agree with

[1] In preparing this section I am greatly indebted to a paper by L. M. HOSKINS on Flow and Fracture of Rocks as Related to Structure. Without his discussion this section would have been far more imperfect than it is. PROFESSOR HOSKINS' entire paper will appear in connection with my own full paper in the Sixteenth Annual Report of the U. S. Geol. Survey.

[2] The part of this paper covered by the contents below this point will appear in the following number of the JOURNAL.

that ordinarily given in the text-books, but it is believed that the restriction is a gain for accurate discussion. The structure corresponds to Sorby's "ultimate structure" cleavage.[1]

Fissility is here defined as a structure in some rocks by virtue of which they are already separated into parallel laminæ in a state of nature. The term fissility thus complements cleavage, and the two are included under cleavage as ordinarily defined. Where a rock is finely fissile it may be called foliated. Fissility corresponds in part to Sorby's "close joints" cleavage.[3]

The terms slate and schist, slaty and schistose, slatiness and schistosity, are retained with their usual significations. A slate may be defined as a rock having the property of cleavage or fissility, or both combined, the rock parting into layers with relatively smooth surfaces. In slates the mineral particles are usually of small size. A schist is a rock having the property of cleavage or fissility, or both combined, the rock parting into layers with rough or wavy surfaces. In schists the mineral particles are larger than in slates. As is well known, there are all gradations between slates and schists. In origin and essential characters the two have many properties in common. Schistosity, however, indicates more severe metamorphism than slatiness. It follows, from the above definitions, that a slate or a schist may have the property of cleavage or of fissility or of both combined. When both are present they may be parallel or intersecting. Both may occur in the same slate or schist in more than one direction.

It is not the aim here to inquire fully as to the manner of development of cleavage and fissility. Starting with the results reached by Phillips,[2] Sharpe,[3] Sorby,[4] Tyn-

[1] On Some Facts Connected with Slaty Cleavage, by H. C. SORBY, Rept. British Association for the Advancem't of Sci., 27th meeting, 1857, pp. 92–93 of Transactions.

[2] Report on Cleavage and Foliation in Rocks, and on Theoretical Explanations of these Phenomena, JOHN PHILLIPS, British Association for the Advancement of Science, 26th meeting, 1856, Proceedings, pp. 369–396.

[3] On Slaty Cleavage, DANIEL SHARPE, Quar. Jour. Geol. Soc. Lond., 1846, Vol. III, pp. 74–105; Vol. V, 1849, pp. 111–129.

[4] Anniversary Address of the President, HENRY CLIFTON SORBY, Quar. Jour. Geol. Soc. Lond., 1849, Vol. XXXVI, Proceedings, pp. 68–92.

dall,[1] Heim,[2] Daubrée,[3] Harker,[4] Becker,[5] and others, it is the purpose to inquire into the attitudes of cleavage and fissility, the causal difference between the two, and the relations which these structures have to others. The investigators mentioned have shown that cleavage and fissility are usually closely connected with folding, being one of the results of compression. It has been held (pp. 195–213) that there are great differences in the manner in which masses of rock respond to compression, depending upon depth and upon whether they are homogeneous or heterogeneous.

Sorby explains rock-cleavage as mainly caused by the rotation of mineral particles, and especially mica, so that their longer diameters and the cleavage of the mica particles are normal to the greatest pressure. The rock readily parts along the greater dimensions and cleavage of the mineral particles. The minute mica plates were supposed to be fragmental particles deposited in the plane of bedding, and to have been rotated by the movement of the rock to a position normal to the pressure. Sorby also showed that the laminar hydrous silicates, such as chlorite, develop in situ parallel to the cleavage. He did not think that this was true of mica in slates, but believed that the parallel mica flakes of mica-schist form in situ during the recrystallization of the rock.

Sharpe and Tyndall explain cleavage as due to the flattening of the mineral particles by pressure, so that they have a parallel arrangement with their shortest axes in the direction of greatest pressure. This cause and the causes given by Sorby

[1] The development of Slaty Cleavage, JOHN TYNDALL, Philosophical Magazine, 4th Ser., Vol. XII, pp. 35–48, 1856.

[2] Mechanismus der Gebirgsbildung, ALBERT HEIM, Band II, 1878, pp. 51–74, mit einem Atlas.

[3] Géologie Expérimentale, by A. DAUBRÉE, Vol. I, pp. 391–432, Paris, 1879.

[4] On Slaty Cleavage and Allied Rock Structures, with Special Reference to the Mechanical Theories of their Origin, ALFRED HARKER, British Association for the Advancement of Science, 55th meeting, 1885, Proceedings, pp. 813–852.

[5] Finite Homogeneous Strain, Flow, and Rupture of Rocks, by G. F. BECKER, Bull. Geol. Soc. Am., Vol. IV, 1891, pp. 13–90.

have ordinarily been regarded exclusive of each other, but it is believed that they may be mutually supporting.

My microscopical study of both cleavable slates and schists has convinced me that in the interstices, and by the decomposition of the larger particles, new minerals, and especially mica, abundantly develop with similar orientation and with their longer diameters or cleavage, or both, parallel to the flattened or rotated original particles. The innumerable parallel minute flakes of cleavable minerals in slate, especially mica and chlorite, which are almost universally present, are in no case detrital, so far as observed by me, but have developed in situ. Usually it is easy to discriminate the large, comparatively sparse, fragmental mica plates, if any are present, from those which are autogenic. As soon as a new mineral particle has developed it is subjected to flattening and rotation precisely as is an original mineral particle. This parallel arrangement of minerals developed in situ is probably the most important single cause of cleavage.

Not infrequently unmodified igneous rocks have the property of rift or cleavage more or less perfectly developed. In all cases observed by me this capacity is due to the arrangement of the mineral particles with their longer diameters in a common direction or to their similar crystallographic orientation, or both. In the case of cleavable minerals, the particles which are similarly oriented give the rocks a capacity to part parallel to the direction of readiest mineral cleavage, and this tendency is more marked if the greater dimensions of the mineral particles accord with their cleavage. In some cases, in which there is a rift in two directions, this is due either to cleavage in the mineral particles in two directions or to cleavage of them in one direction and their parallel arrangement with longer axes in the other direction. Hornblende is one of the minerals which sometimes produces a cleavage by having very numerous crystals with their longer diameters in a common direction. Feldspar is one of the minerals which produces cleavage on the same principle as hornblende, but which also in some cases gives a rock-cleavage as a result of the cleavage of the mineral particles.

From the foregoing it is believed that *rock-cleavage is due to the arrangement of the mineral particles with their longer diameters or readiest cleavage, or both, in a common direction, and that this arrangement is caused, first and most important, by parallel development of new minerals; second, by the flattening and parallel rotation of old and new mineral particles; and third, and of least importance, by the rotation into approximately parallel positions of random original particles.* The propriety of the definition of rock-cleavage as first given is therefore evident. It is always due to a capacity to part, and very frequently the parting does occur by the actual cleavage of the mineral particles.

DEVELOPMENT OF CLEAVAGE IN HOMOGENEOUS ROCKS.

Becker has recently rediscussed the origin of cleavage, and concludes that it always develops in the shearing planes rather than in the normal planes. Even in the case of the experimental development of a cleavage-structure in wax, which is strictly normal to the pressure, the structure is explained as developing in the shearing rather than in the normal planes.

As will be seen below, it is my own conviction that a structure develops in the normal planes under certain conditions, and that under other conditions structures develop in the shearing planes, as advocated by Becker. The first is believed to be a deep-seated phenomenon of the zone of flowage; the second is believed to be a more superficial phenomenon in the zone of fracture. In other words, as already stated, it is thought that under the term cleavage two entirely distinct structures of different origins have been confused. Theories which explain or partly explain one of these structures have been extended to cover both of them, because it was not understood that they are different.

Rocks when deformed under great weight flow as a plastic solid, and under these circumstances, as shown by the geologists above cited, the property of cleavage is developed. At all times the particles of the rock are welded together. Fissility will not form, for by the supposition the rocks are so deeply buried that no crevices can exist. In the formation of flow-

age cleavage, or cleavage proper, as the term is here used, the thrust may be from one or more than one direction. It may vary in force both horizontally and vertically. In any case there is flow of the rock-mass in the direction of least resistance. If the force be applied so that there is uniform shortening in one direction, as in the case of a rigid piston, the elongation is at right angles to the direction of thrust, or in the normal planes. This may be called *pure shortening* (Figs. 1 and 2). By pure shortening is meant the particular kind of non-rotational distortion illustrated. The volume remains unchanged, the shortening in one direction being compensated by equivalent elongation at right angles to this. In this kind of deformation, while there is no differential movement or shearing in the normal planes, shearing does occur along all of the intersecting diagonal planes. It makes no difference whether the movement is wholly from one end of the mass or in part from both ends. But when the lateral force varies greatly at varying depths the deformation may vary from pure horizontal shortening to a nearly horizontal differential movement combined with shortening (Figs. 5 and 6). Such inclined differential movement is dependent both upon the varying force of thrust in passing from higher to lower horizons and upon increased friction with greater depth, due to gravity, which acts as an opposing force. In the case last illustrated the deformation is a simple shear.[1] The deformation here called pure shortening is defined by Becker[2] as a shear, and a shear, as just defined, is called by him scission.

Ordinarily, at any place in the rock-mass the three principal compressive stresses are unequal. If the differential stress surpasses the elastic limit of the rock it produces shortening in the direction of greatest stress, elongation in the direction of least stress, and shortening or elongation in the direction of mean

[1] Text-book of the Principles of Physics, by Alfred Daniell, 3d edition, 1894, p. 78. Macmillan & Co., London and New York. Elementary Text-book of Physics, Anthony and Brackett, 4th ed., 1888, pp. 113–114. Treatise on Natural Philosophy, Thompson and Tait, new ed., 1890, Part 1, pp. 123, 124.

[2] Finite Homogeneous Strain, Flow, and Rupture of Rocks, by G. F. Becker, Bull. Geol. Soc. Am., Vol. IV, 1891, pp. 22–25.

stress, depending upon whether the latter is nearer the maximum stress or the minimum stress. The phenomena subsequently described appear to show that there is more frequently elongation than shortening along the direction of mean stress. It follows that as a result of flowage there is usually one direction

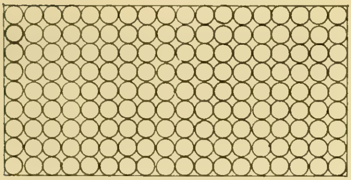

FIG. 1

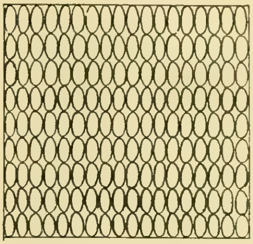

FIG. 2

Figs. 1 and 2. Showing theoretical change in arrangement and form of particles when uniformly shortened by hydrostatic viscous flow.

of shortening and two of unequal elongation. The plane of the minimum and mean stresses is believed to be the plane of cleavage.

A coherent slate, which has the unmodified property of cleavage as here defined, shows but a single marked structure. This structure in the dense slates is often nearly normal to the direction of the greatest shortening of the strata. In the many instances in which cleavage is everywhere nearly parallel to intrusive igneous masses, there seems to be no escape from this conclusion. In such cases a zone of slate or schist surrounds a granite or other mass, the secondary structure varying in direction through 360°, thus making a circle about the intrusive core. The cleavage is therefore at each point nearly at right angles to the greatest pressure. Such zonal cleavage about batholites has been described in this country at various localities. The cleavage in the mica-schist adjacent to the granite core of the Black Hills is everywhere parallel to the igneous mass. Lawson has described like phenomena at many places in the mica-schists of Ontario. The secondary structure is everywhere parallel to the adjacent igneous masses. Emerson finds that the same relations obtain between the secondary structure and the intrusive granites

in Massachusetts. Similar phenomena have been described in other countries at localities too numerous to mention. In all of these cases there can be no doubt that the magmas were under hydrostatic conditions and transmitted their pressures at every point normal to the rocks with which they were in contact. There would therefore seem to be no escape from the conclusion that in such cases the secondary structure developed in planes normal to the pressure.

In homogeneous slates having cleavage it is not usually possible to follow the particles through their movements to their final positions. However, in rocks which are not so nearly homogeneous there are numerous minor plications. Where these plications are arranged in a symmetrical fashion, that is, do not have one set of limbs longer than the others, they give strong evidence that the thrusts were in opposite directions and normal to the secondary structure. If the rock were homogeneous the crumplings would disappear and the movement of the particles would more nearly follow the law of plastic flow. Such deformation of the particles may be without differential movement normal to the pressure, and is illustrated by Figs. 1 and 2 in an ideal case. It is not necessary that the particles be of the same size or of the same strength. As is known by macroscopical study of the schist-conglomerates and by microscopical study of ordinary slates and schists, if the movement continues far enough the old mineral particles are flattened, or flattened and rotated, into parallel positions. New minerals develop with similar orientation. Therefore, as a consequence of the flowage of the stratum, the induced arrangement of the particles necessarily produces a capacity to cleave in the plane of the two longer axes of the mineral particles, as in this direction the rock may part between them.

In the case of forces resulting in rotatory movement, the structure may be explained as developing in the normal planes as in the case of pure shortening. The direction of shortening of any small area varies in its relation to the component particles at each successive moment. This variation may be due

to the work of stress-couples producing simple shearing, to a change in the direction of pressure, or to a rotation of the area concerned, or two or all combined. The final result, as shown by Professor Hoskins, is to deform a given homogeneous area as though it were shortened in but a single direction, and after this was rotated (Fig. 3). The cleavage is at right angles to the direction of greatest shortening of the area in its final position,

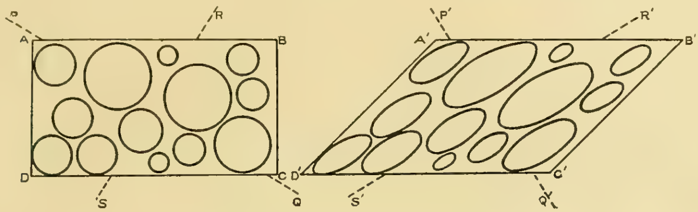

FIG. 3.—A portion of a bed *ABCD*, containing round pebbles, is shearing into the form *A'B'C'D'*. The cleavage is parallel to *R'S'*. The result is the same as through the material had been flattened by pressure along *PQ*, and the mass afterwards rotated until *RS* fell in line with *R'S'*. After Hoskins.

this structure being due to the capacity to part parallel to the greater dimensions of the mineral particles. This resultant position is not normal to the final direction of greatest pressure, but at any given moment the deformation occurring is itself normal to the pressure. Newly developing minerals also tend to form at any moment with their shortest axes in the direction of pressure, and are rotated by the simple shearing exactly the same as the original minerals. Therefore the shortest axes of both new and old minerals are in the same direction. Thus the cleavage develops strictly in the normal planes, but its position by the rotation of simple shearing is inclined to the final direction of pressure.[1]

[1] It is admitted to be somewhat difficult to understand the precise nature of the ultimate interior movements by which pure shortening involving shearing along two sets of intersecting diagonal planes produces a structure normal to the greatest pressure. However, Professor Hoskins shows that during pure shortening it is only for a moment that any given plane is one of maximum tangential stress and pure sliding, and that all planes inclined to the greatest pressure are shearing planes (Figs. 1 and 2). If some structure should be produced along the shearing planes in the zone of flow, one would not expect a structure in a single direction, but structures in an indefinite number of direc-

I therefore conclude from analysis, from experiments upon viscous and plastic bodies, from observations in the field, and from studies with the microscope, that I am justified in the statement that *the secondary structure of a rock which is deformed by plastic flow develops in the plane normal to the greatest pressure, and that this structure is true cleavage.*

We thus see that in both the case of pure shortening and the case of shortening combined with rotation the secondary structure is parallel to the greatest dimensions of the mineral particles. This parallelism may be macroscopically observed at very numerous localities in which schist-conglomerates occur. Some of the more important of these are the Hastings district of Ontario, Green Mountains of Vermont (Fig. 4), Felch Mountain district of Michigan, many localities in the basal conglomerates of both the Upper Huronian and Lower Huronian in the Marquette district of Michigan, the Black Hills of Dakota, and the Front Range of Colorado.

In different localities the degree of flattening of the pebbles varies from a small amount to that in which the pebbles are

tions. In most cases where a solid mineral particle or an aggregate of mineral particles having an individuality is much flattened, we have evidence of the very complicated shearing along many intersecting planes. The deformation, if carried far enough, ordinarily does not produce a single, or even two structures, but complete granulation. The sum total of the sliding along all of the shearing planes is to shorten the diameter of any given area in the direction of greatest pressure and to elongate it at right angles to this. During this deformation a given mineral particle may have become a multitude of mineral particles. However, the multitude in the aggregate differs in composition and consequently in strength from the adjacent similarly flattened areas. Moreover, many of the newly formed individual particles have similar forms in like positions. Oftentimes the readiest cleavage of many of the particles accords with their greater diameters. The result is that there is an easy parting or cleavage along the greater dimensions of the flattened areas and the greater dimensions of the newly developed particles. Even if the material is absolutely homogeneous so far as we can discover, the same principle applies, as shown by Tyndall for wax. Analogous to this is the case of stretched or compressed viscous Canada balsam, which takes on a structure not in the shearing planes, but parallel to the tension or at right angles to the pressure, as shown by polarized light. As shown by Professor Hoskins, the case of simple shearing does not differ from that of pure shortening except in that the mass as a whole is rotated (Fig. 3). If the above is true, it is clear that all combinations of pure shortening and of simple shearing in the zone of flow result in producing a cleavage which develops normal to the greatest pressure.

transformed into leaf-like areas. Everywhere and in all grades of change the secondary structure accords with the longer diameters of the flattened pebbles. The some phenomena have been observed by me in microscopical studies upon fragmental particles in hundreds of sections from the semicrystalline formations from many parts of America.

According to Becker's explanation of slaty cleavage, there is

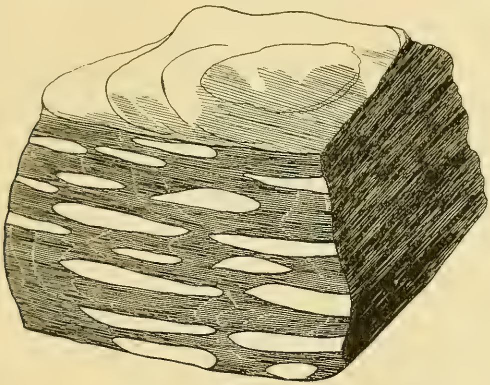

FIG. 4

Fig. 4. Schist conglomerate, showing pebbled character when cut transverse to the major direction of shortening, and gneissoid character when cut in other directions, from Plymouth, Vt., after Hitchcock.

an important discrepancy between the direction of the structure and the greater diameters of the flattened mineral particles.[1]

If the above observations are correct, it would seem that there is no escape from the conclusion that the secondary structure which I here describe as cleavage is not developed in the manner described by Becker and cannot be explained by his theory. I therefore return to the old explanation of the English geologists—which perfectly accords with the facts—that this secondary structure develops in planes normal to the pressure.

In further confirmation of this explanation are certain phenomena described to me by Diller and Keith.

Diller makes the following statement:

[1] Finite Homogeneous Strain, Flow and Rupture of Rocks, GEORGE F. BECKER, Bull. Geol. Soc. Am., Vol. IV, pp. 55–66.

At Crystal Lake, on Hough's Peak, Plumas county, California, is a conglomerate that is immediately associated with slate. Slaty cleavage is well developed in the latter, and also in the conglomerate. The greater diameters of the flattened pebbles are always in the cleavage planes. The harder pebbles are less elongated than the softer ones, and are frequently fractured, the fractures being diagonal to the cleavage.

The probable explanation of the phenomena is that the cleavage develops in the normal planes and the fractures develop in the shearing planes, as explained by Becker. At the same depth and pressure the softer parts of the rock were under conditions of flow and the hard pebbles under conditions of fracture.

Keith makes the following statement:

Near Blowing Rock, N. C., is a mashed porphyritic granite in which porphyritic crystals of feldspar are flattened in various degrees, and their greater diameters are upon the average parallel with the secondary structure. In many cases the feldspar crystals are fractured in a direction diagonal to the cleavage, and in some cases in a single feldspar crystal there are two sets of diagonal fractures approximately at right angles to each other and each inclined about 45° to the cleavage.

The phenomena therefore correspond precisely to the idea of a pressure normal to the cleavage, which at the same time produced fractures in the more rigid feldspar crystals along the maximum shearing planes. As in the slate described by Diller, the weaker matrix was under conditions of flowage at the same depth that the more rigid feldspar crystals were under conditions of fracture.

It is a very common phenomenon in slates and schists, both macroscopically and microscopically, for the direction of the secondary structure to wrap around the harder particles. As a hard grain or pebble is approached the cleavage structure in the matrix opens out on each side of the grain, envelops it, and closes in again beyond it. The structures nowhere intersect, although upon opposite sides of a particle near the ends they converge, and in passing toward either end they turn and become parallel. They would intersect if continued in their original direction. While the cleavage of the matrix, where there are many harder particles, constantly varies in direction, it nowhere intersects. Its average direction is the same as that of other

parts of the rock in which resistant particles are absent. Because the structure of the cleavage, where hard particles are present, simulates a mesh structure, loose observation might lead to the conclusion that there are present two intersecting structures. The prime characteristic of a true mesh structure is that two diagonal structures shall intersect. As shown subsequently (p. 465), interesting diagonal fissility may develop in the shearing planes.

The deviation of cleavage about hard particles is explained by the fact that the more resistant grains act as transmitters of forces. At any given point at the exterior of a hard particle the direction of greatest pressure is normal to the grain, and hence the peripheral arrangement of the cleavage about the grain. The principle is precisely the same as that explaining the development of zonal cleavage about intrusive batholites. (See pp. 455–456.)

The crucial point in deciding whether there is a structure which develops in the normal plane is the simple matter of fact as to whether or not the flattening of the original particles corresponds with this structure. In testing this point it is best to take examples in which the flattening of the particles is not too great (see Fig. 4), else the lessening discrepancy between a possible structure called cleavage by Becker,[1] developing in the planes of "maximum tangential strain," and that regarded as cleavage by me, developing in the normal planes, may be overlooked. As already explained, I hold that the facts of the field accord with my position. Upon this crucial point of fact I ask the observation of geologists, for by the facts of occurrence must be judged the adequacy of the explanation offered as to the manner of action of the forces which produce cleavage. It is believed by me, as will be seen, that the theory that cleavage is developing at any given moment normal to the pressure fully explains all the diverse facts of true cleavage in both homogeneous and heterogeneous rocks.

Fin te Homogeneous Strain, Flow and Rupture of Rocks, GEORGE F. BECKER, Bull. Geol. Soc. Am., Vol. IV, pp. 55–66.

The amount of shortening of the area of a rock-mass necessary to produce the property of cleavage may not be great in a slate, as shown by the amount of distortion of the bedding. In proportion as the shortening becomes greater the rock is apt to change from a slate to a schist. If the process of shortening continues until a schist is produced, it is often difficult or impossible to estimate the amount of horizontal shortening of the strata, but it is certain from observation that it is usually considerable, perhaps to one-half or one-third of the original. This is shown by the plications of layers of a slightly different color which are cut by the schistosity. If plicated layers such as often occur in schists were straightened out, they would require a distance across the schistosity two or three times as great as at present.

It is very rare indeed that any rock is so homogeneous that the unmodified law of normal flow perfectly applies as above given. Among the sediments argillaceous rocks most nearly approach homogeneity. The massive rocks, however, still more nearly approach homogeneity. But even these are not strictly homogeneous, being composed of mineral particles of different sizes and characters. However, these particles in many instances are uniformly flattened and readjusted, so that the mass in a large way almost perfectly obeys the law. A mashed massive rock having cleavage but not fissility is a solid, strong schist, and it is in this class of rocks that cleavage in a uniform direction as the result of normal plastic flow is best exemplified.

Rarely rocks show an almost equal capacity to part in any direction parallel to fibers. In these cases the microscope shows that the mineral particles are very long in the fibrous direction, and have about the same average magnitude in all directions at right angles to their greatest diameters, instead of having two definite directions of mean and minimum diameters at right angles to each other, as is ordinarily the case in slaty cleavage. As pointed out by Professor Hoskins, this structure is explained by the deforming or maximum pressure being equal or nearly equal throughout a circle of revolution in all directions

perpendicular to the fibrous structure and by less pressure in the direction parallel to the fibers. This results in shortening in all radial directions and elongation at right angles to this, and thus the fibrous structure is formed normal to the plane composed of the radial direction of greater pressure.

It has been seen on a previous page that unmodified igneous rocks may have the capacity to cleave, and that the structure is similar to a secondary structure in sedimentary rocks. There is not so great a difference between the two in this respect as might at first be supposed. The arrangement of the mineral particles in the igneous rocks is caused by the similar original crystalline orientation of the mineral particles produced by unequal stresses in three dimensions and by the rotation of flowage. In the sedimentary rock the same is true, but the flatness of the particles is due to another cause. The chief difference is, however that the lava is a viscous liquid and the crystallized rock a plastic solid. The manner in which the parallel minute mineral particles which produce cleavage in igneous rocks change their direction in passing around a large porphyritic crystal is as similar as possible to the way in which laminar mica scales in a slate or schist change in direction in passing around a large refractory grain. In both cases the material wraps around the rigid particles which were sufficiently strong to partially or wholly resist deformation.

The above explanation of cleavage makes this structure also analogous to the capacity to part along bedding planes in sedimentary rocks. As each erosion particle has unequal diameters, it comes to rest in most cases with its longer diameters in the plane of bedding, thus giving at the outset a laminated structure. This structure may be emphasized by the pressure of gravity. It therefore follows that the unaltered sedimentary rock ruptures more readily along its bedding plane than elsewhere. That the capacity to part parallel to bedding is less marked than parallel to the cleavage of slates and schists is due to the fact that the ratio of the minor to the mean and major diameters of the mineral particles is not so large and the regularity of the parallel

arrangement not so nearly perfect in the original sediment as in a slaty or schistose rock. If a maximum deforming force be normal to the bedding, as it may be in some cases, the original imperfectly parallel arrangement of the mineral particles, with their longer axes in the direction of bedding, would be so much done toward producing a cleavage, and the result would be to give a more highly developed secondary structure parallel to the bedding with a given amount of movement than would result from the same deformation in a different direction.

In some instances, as has been seen, observations show that the conjoint action of tangential thrust and friction throughout considerable masses of rocks was apparently such as to give approximately uniform shortening of the strata in one direction. The material is confined on all sides, and its deformation is that of a plastic solid. The direction of least resistance is toward the surface of the earth. The direction of mean resistance is at right angles to the minor thrust and parallel to the surface. Consequent upon the flow, the mineral particles, new and old, at any particular point arrange themselves with their longer axes in the plane of these directions. This plane is vertical, or nearly so, and almost at right angles to the major thrust. Therefore, in approximately homogeneous rocks cleavage is frequently vertical or highly inclined, and hence intersects the bedding. This may be called *cross cleavage*.

But supposing the lateral thrust to vary greatly in depth, and considering that friction increases with depth, the movement may vary, as explained above, from upward plastic flow to differential movement in a horizontal direction. In this change we have passed from a pure shortening to a simple shearing. If the movement was sufficient the cleavage would be nearly parallel to the bedding, and it may be called *parallel cleavage*. In the case of parallel shear the cleavage would accord in its principle of development with that of parallel cleavage in heterogeneous rocks, subsequently described (see pp. 472–480).

These extreme cases rarely occur. Almost invariably there is a combination of pure shortening with shearing motion. The

combination is ordinarily such as to give steeply inclined cleavage cutting the bedding, and therefore a cross cleavage. There are, however, undoubted gradations between cross cleavage and parallel cleavage. In all cases in nature the final resultant or direction of movement depends upon a union of all the forces concerned.

DEVELOPMENT OF FISSILITY IN HOMOGENEOUS ROCKS.

If a rock be in such a position and under such conditions that it is deformed by regular fracture, it is probable that the secondary structures form in the shearing planes. Just as in the case of cleavage, at any place in a rock-mass the three principal stresses are usually unequal. In the zone of fracture if the differential stress surpasses the ultimate strength of the rock, fracture occurs along the two sets of shearing planes which incline toward the greatest stresses and are parallel to the minimum stress. The planes of maximum shearing stress in the case of normal pressure are 45° from the greatest pressure and are at right angles to each other, but Hoskins shows that the fractures may incline at a smaller angle than this to the direction of greatest pressure, the latter bisecting the acute angle made by the intersecting ruptures. It is only in case the two lesser stresses are equal, or nearly so, that concoidal fractures are produced, such as occur in ordinary building-stone tests of cubes. In this experiment there is one direction of great stress and two directions at right angles to this of very subordinate equal stress.

Hence, in the zone of fracture, where the differential stress surpasses the ultimate strength of the rock, there may be produced a fissility in two sets of intersecting planes equally inclined to the greatest pressure. It is well known that a fissility in two directions occurs in many homogeneous rocks, and such structures have doubtless developed along the shearing planes under this law.

In case the direction of greatest normal pressure is nearly horizontal, the planes of fissility would be at angles of about 45° with the horizon. However, as no rocks are strictly homo-

geneous, and as the direction of greatest normal force is always compounded of thrust and gravity, the directions of the fissility may vary considerably.

In case the parting is very close, the rock is foliated. Each lamina moves slightly over the adjacent laminæ. The rubbing of the laminæ over one another, due to the differential movement, gives the slickensided surfaces which are so common on both sides of the parted laminæ. The more intense the movement, the thinner and more brilliant do the folia become. Since partings are usually inclined to the bedding, this structure may be called *cross fissility*.

In passing from the zone of fracture to the zone of flow it is to be expected that all gradations would be found between the development of cleavage in the normal planes and the development of fissility in the shearing planes. This point is discussed later. (See pp. 480–481.)

Frequently fissility forms in lithologically homogeneous rocks in which the property of cleavage had already been developed, and which by subsequent denudation are brought so near the surface that the superincumbent weight is less than the strength of the rocks. When subjected to stress under these circumstances numerous fractures develop along the cleavage planes. This occurs because fractures take place so readily along these planes, and because the chances are always that these are shearing planes, although they may not be those of maximum shearing stress.

This may be the case although the direction and force of thrust may not have varied. The direction of greatest normal pressure, combined of gravity and thrust, would be in a different direction when the rocks are in the deep-seated zone of flowage and when they are in the superficial zone of fracture. Thus, cleavage in the normal planes would pass into the shearing planes as denudation progressed.

In cases in which the fissility develops along a prior cleavage, the fissility parallel to these planes would be marked. The fracturing along the other set of diagonal shearing planes, not

having the advantage of a previous cleavage, would be much less marked, the deformation perhaps largely occurring by considerable movements along a few planes of shearing. In this case the infrequent cracks may properly be called joints. In the planes of fissility secondary to cleavage the folia slip over one another just as in the case of originally developed fissility independent of cleavage, producing slickensided surfaces, and the rock develops a "fault slip" cleavage or "ausweichungs" cleavage. In the majority of cases in which the fissile laminæ are close together and have a uniform direction for a considerable area, it is probable that the structure first developed as true cleavage in the normal planes, and that a later movement, when the rock was nearer the surface, developed the fractures along the shearing planes. The structure is thus a product of the forces producing cleavage and those producing fissility working successively under different conditions.

As will be seen below, fissility may form, in a manner similar to its development parallel to cleavage, parallel to planes of weakness of any other kind, as, for instance, bedding.

The directions of the fissility are therefore dependent upon the direction of the forces, upon whether they are equal or unequal, upon the superincumbent load and the consequent friction, upon the cleavage and other previous structures, and upon previous folding.

If fissility develop along cleavage, as this structure is usually steeply inclined, the fissility will be in the same direction. That great thrust faults sometimes develop with nearly horizontal hades, or even parallel to bedding, is well known. Multiple minor thrust faults or fault slips producing fissility may similarly develop with flat hades, upon the same principles as cleavage, in a like direction, and thus produce a fissility nearly or quite horizontal, or parallel to bedding. It is therefore clear that the structure may vary from a vertical to a horizontal attitude. There are therefore all gradations between cross fissility and parallel fissility, described in the following number (Fig. 7), just as between cross cleavage and parallel cleavage. In

the case of parallel fissility the movement may be compared to the differential movements of a ream of paper which under load

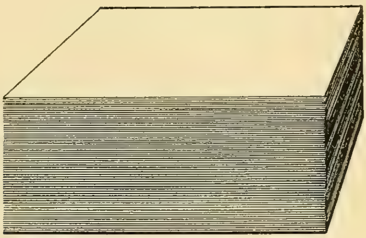

FIG. 5

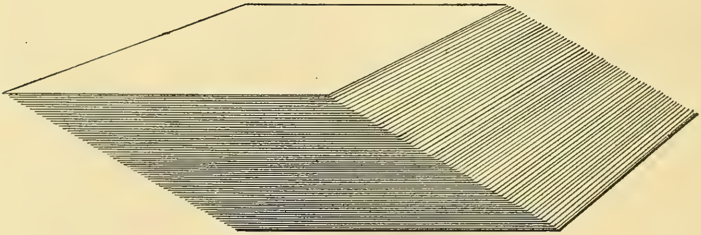

FIG. 6

FIGS. 5 and 6.—Theoretical deformation of laminated rock by uniform differential movements parallel to a previous structure.

is pushed unequally forward from one end, the differential movement between any two successive sheets being the same. While the bottom sheet may be shoved one-tenth of an inch, the top sheet may be shoved 10 inches (Figs. 5 and 6). Between the bottom and the top the amount of forward movement would vary regularly from one-tenth of an inch to 10 inches. While the differential movement between any two sheets is the same, each sheet gains all the forward movement of all the sheets below.

Where fissility develops, either as an original or secondary structure, rubbing usually occurs between the mineral particles

along the sides of the laminæ. As a result, the minerals receive an elongation in the direction of greatest movement, a less elongation in the direction at right angles to this and in the plane of movement, but are shortened at right angles to the plane of movement. Also new minerals which develop are controlled in the same manner. If the fissility be secondary to cleavage, the minerals were previously oriented with their two longer axes in the plane of differential movement, and the slipping of fissility but emphasizes an arrangement of the mineral particles which already existed.

DEVELOPMENT OF CLEAVAGE AND FISSILITY IN HETEROGENEOUS ROCKS.

When a set of layers, either sedimentary or not, of different lithological character are folded, and cleavage or fissility develops in them, the process is not simple.

As the case of alternating sediments is the most important one, and somewhat different from any other, this will be first considered.

The original series, instead of being homogeneous, is composed of beds of different characters; that is, it consists of alternations of mud, grit, sandstone, limestone, etc. Before these rocks are folded the forces of consolidation, cementation, and metasomatism may have been at work. As a result of these prior alterations, combined with original deposition, the strata may have greatly varying strength. The sandstones may have been transformed to quartzites; the grits may have been changed to graywackes; the muds may have been compacted into shales; and the limestones may have become crystalline.

When such a series is folded the accommodations occur mainly along the beds. The greatest readjustments and greatest compression are along the limbs of the folds (see pp. 207–210, and Figs. 2, 3, and 5 of my first article). Each layer shears over the one next below under enormous stress. The necessary movement at first is largely concentrated in the weak layers between the beds of stronger material (Fig. 7). The

shearing extends from these into the harder ones, for when motion has once begun along a certain set of planes, that very movement weakens the rocks along these planes and makes it easy for the forces applied in any direction to be decomposed into forces producing further movement along the same planes.

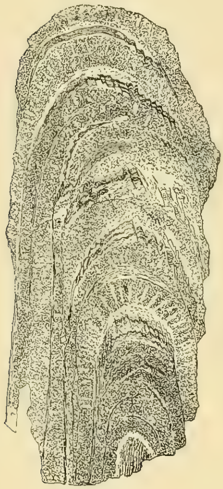

FIG. 7

Parallel fissility on the limbs of the folds and cross fissility on the anticlines, and gradations between the two. After Heim.

The deformation is mainly by folding, but on the anticlines, where the material is partly relieved from stress, the deformation is partly by multiple minor faulting.

The maximum force producing shear is composed of horizontal thrust and gravity, and its direction will therefore usually be inclined to any layer in a horizontal position, although if gravity is unimportant as compared with thrust this inclination may be slight. When the layers become tilted this inclination is marked, although the problem becomes more complicated on account of the strength of the individual beds. These tend to decompose the forces which they receive at one point into components parallel and normal to themselves, and transmit the longitudinal thrust to another point. Upon the limbs of the folds the beds are, however, never free from superincumbent weight, and the rigidity of the overlying beds must also be often overcome. Therefore, in nearly all cases of heterogeneous rocks the direction of greatest normal stress is inclined to each layer. There are two classes of cases—those in which the rock bed is in the zone of flowage, and those in which the rock bed is in the zone of fracture. The first afford conditions for the development of cleavage; the second, those for the development of fissility. Between the two there may be gradations.

DEVELOPMENT OF CLEAVAGE IN HETEROGENEOUS ROCKS.

For a given very small area in a stratum the cleavage may vary from parallel to perpendicular to the bedding. If at any moment the direction of greatest normal pressure is in the direction of bedding, the secondary structure will tend to develop at right angles to the bedding. If, on the other hand, the direction of greatest pressure is at right angles to bedding, the cleavage will tend to develop nearly parallel to the bedding. Between these two there will be all gradations. For different beds and for different areas in the same bed the direction of greatest pressure will, at successive times, vary both relatively and absolutely, and therefore the cleavage developing in the normal planes at any given moment will gradually vary in direction. For a small, practically homogeneous area the final resultant will be the same as in homogeneous rocks (p. 457)—that is, the cleavage will be perpendicular to the direction of greatest final shortening.

Having made this general statement, let us inquire more particularly how the forces producing cleavage act in heterogeneous rocks.

As a result of the folding, combined with denudation, the relative amounts of thrust and gravity vary at different times, so that the average direction of greatest normal pressure for a given area also varies. On account of the differing strength of the beds the forces received by them are decomposed to a greater or less degree into directions parallel and normal to themselves, and thus the direction of greatest pressure is varied at each particular point. During the folding process the inclination of the beds is constantly changing, and as a consequence any given small area is being rotated with reference to the direction of greatest pressure. The problem is further complicated by the readjustment between the beds, which constantly changes the relative position of the material with reference to the pressure. Lastly, the readjustment usually takes place mainly within the weaker layers, and this changes by a varying amount the relative positions of different parts of the beds with reference to the greatest pressure. At any given point there

will be a plane in which are the major and mean axes of the mineral particles, and this will be the plane of cleavage. It is evident that this plane will vary in position from place to place. As shown by Professor Hoskins, these conclusions follow from the fact that all of the different compressions, acting in different directions at different times, are equivalent to some single compression acting continuously in one direction, and the shearing motion of differential movement is equivalent to a compression combined with a rotation.

Very frequently the position of the cleavage with reference to the bedding for a given small area will be controlled by the readjustment between the beds. The structure will tend at any moment to develop in the normal planes, but as a consequence of the shearing the material is rotated so that the final direction of cleavage is inclined to the direction of greatest pressure (see Fig. 3). Since the readjustment is mainly concentrated within the weaker layers, the structure may be so rotated in them as to approach parallelism with the beds, while in the adjacent stronger beds, in which there is less differential movement, the structure may be nearly at right angles to the beds ; and at various positions between the cleavage will have intermediate directions. There will thus be developed a cross cleavage in the more resistant beds, which varies by a gentle curve into parallel cleavage in the weaker beds. On opposite sides of the layer the curves are in opposite directions (Fig. 10). By these curves it is easy to determine the relative directions of the movements of the layers.

Directly following from the above we have the explanation of the step cleavage[1] of the older authors and of Becker,[2] and of the differential cleavage of Dale. In this case the change in the direction of cleavage, instead of being gradual, as it is in rocks of gradually varying plasticity, is somewhat sudden in passing from one bed to another differing in rigidity. As a result of

[1] On Slaty Cleavage and Allied Rock Structures, with Special Reference to the Mechanical Theories of their Origin, ALFRED HARPER, Brit. Assoc. Adv. Sci., 55th meeting, 1885, Proceedings, pp. 829–830.

[2] Finite Homogeneous Strain, Flow, and Rupture of Rocks, GEORGE F. BECKER, Bull. Geol. Soc. Am., Vol. IV, pp. 84–87.

the shearing motion the cleavage is rotated more in the more plastic layers and less in the less plastic layers. Hence, *in heterogeneous rocks having cleavage, in a soft layer the cleavage more nearly accords with bedding than it does in a hard layer.*

To summarize: We have the absolute direction of greatest pressure varying; as a consequence of the difference in the strength of the beds we have the direction of greatest pressure varying from place to place; we have the material of any given area on the limbs of folds rotated with reference to the direction of greatest pressure; and finally, we have variable differential motion between the beds, which momentarily changes the direction of the area with reference to the pressure. However, Professor Hoskins shows that these all combine to produce at any given point a shortening of the particles in one direction and an elongation in one or both directions at right angles to this. Newly developed mineral particles have similar orientations. At any point perpendicular to the final position of the shortest axes of the mineral particles there will be the property of cleavage. As the differential movement at any given place is parallel to the dip, the longest axes of the mineral particles will be in the plane of cleavage and in the direction of dip. The mean axes of the mineral particles will be in the same plane but in the direction of the strike of the cleavage.

If before the folding a cleavage had already developed parallel to the bedding by deep-seated metasomatic change or by flattening parallel to the bedding below the level of no lateral stress, as suggested in the following number of this JOURNAL, this would modify the direction of the secondary structure, making it more nearly parallel to the bedding than it would otherwise be.

In areas of symmetrical or gently inclined folds and in homogeneous rocks the shortening is approximately in the line of the horizon and the cleavage therefore steeply inclined. In heterogeneous rocks the differential movement between the layers, as has been pointed out (pp. 207–208 of my first article), is ordinarily upward for a higher stratum as compared with the one

next below it. In the case of abnormal folds (see pp. 330–332 of my second article) this differential movement is emphasized. Consequent upon the differential movement upon the limbs of the fold in weak beds where the shearing motion is largely concentrated, the cleavage is locally flatter than in homogeneous rocks. Whether the rocks are homogeneous or heterogeneous the rotation is in opposite directions on opposite sides of anticlinal arches or synclinal troughs, being outward for an anticline and inward for a syncline; therefore *on opposite limbs of a fold the cleavage usually dips in opposite directions. Upon opposite sides of an anticline the cleavage usually diverges downward, and on opposite sides of a syncline it usually converges downward.*

Ordinarily the rotation of shearing will not go far enough to bring the cleavage into correspondence with bedding, and its dip will be steeper than the dip of the strata; hence, *on opposite sides of a fold the variation in the dip of cleavage is less than the variation in the dip of bedding.* However, in the case of much-compressed normal composite folds (Figs. 8 and 11 on pp. 321 and 323) the force of gravity and unequal thrust control the direction of the moving force, and consequently the form of the secondary folds. In this case the cleavage may be rotated from its ordinary position, and upon opposite sides of the anticlinorium the cleavage may converge downward and upon opposite sides of the synclinorium may diverge downward. This applies as well to the central fan folds as to the minor folds on the flanks (Fig. 9, on p. 321).

It has been pointed out (p. 341) in the case of much-inclined or overturned folds, that the resultant differential movement or shearing between the strata on the steeply inclined or overturned limb may be down for a geologically superior stratum as compared with an inferior stratum. It follows that the shearing on both limbs of the fold is in the same direction, and therefore that *in regions of overturned monoclinal folds the cleavage may be rotated in the same direction throughout, and will hence be monoclinal.* Since on monoclinal folds the differential movement is great on the longer and flatter limb of the fold, the cleavage may be

rotated so as to be almost parallel to bedding, but usually is somewhat steeper. As the resultant differential movement is comparatively slight on the steeper, shorter limb, the cleavage usually cuts across the bedding at a considerable angle and is steeper in reference to the horizon. On the opposite limbs of monoclinal fan-shaped anticlines the cleavage may be nearly parallel, or may even converge downward, and on the opposite limbs of monoclinal fan-shaped synclines the cleavage may be nearly parallel, or even diverge downward.

This contrast with symmetrical folds is due to the continuous rotation in the same direction of the cleavage along the arch limb of the fold combined with the rotation in the reversed limb, first opposite to and afterward in the same direction as that on the arch limb. As in the case of symmetrical folds, the variation in dip of cleavage is less than the variation in the dip of bedding. In districts in which cleavage and bedding have the relations above described, on the longer arch limbs it is often difficult to discriminate between the two, but it is believed that the cleavage is usually slightly steeper than the bedding, as already explained. On the steep or reversed limbs the minor crenulations of the strata are usually easily detected intersecting the cleavage.

When rocks are openly folded the discrepancy between cleavage and bedding is usually great. As the folding becomes closer the average discrepancy becomes less. If the compression goes so far as to form isoclinal folds the bedding and cleavage may nearly correspond upon the limbs of the folds, but the two will be at right angles to each other upon the crests of anticlines and in the troughs of synclines (Fig. 7). When the compression is so great as to form plicated folds, the changes in the direction of bedding being very sharp, the discrepancy between bedding and cleavage will be slight. However, the discrepancy is real and important. The cleavage in this case may be about parallel to the axial planes of the folds, and will cut the beds at a very acute angle. In many districts where cleavage has been described as everywhere according with bed-

ding, and the two do approximate but not exactly accord in direction upon the limbs of the folds, a close examination shows that on the crests of the anticlines and in the troughs of the synclines the two structures intersect each other.

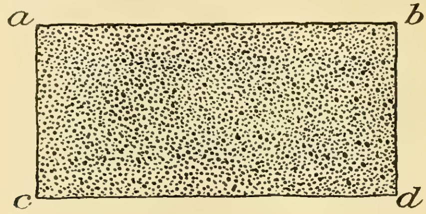

FIG. 8

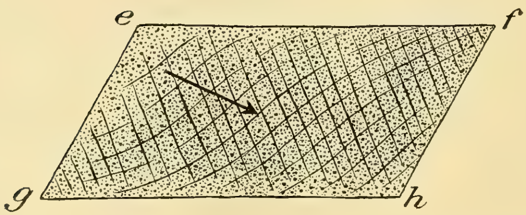

FIG. 9

FIGS. 8 and 9.—Diagram showing development of fissility along the longer and shorter diagonals of a deformed portion of a rock stratum.

In the center of stratum the fractures are in the planes of greatest shearing, but on the outside of the layer the fractures are in lesser shearing planes, the direction of fracture being controlled to some extent by bedding.

At the beginning of the process it may be noted that the shortening is at right angles to the bedding. At the end of the process the shortening is parallel to the bedding. Thus the work first done is partly undone. The resultant position of the shorter axes of the mineral particles in reference to the bed is intermediate between the two extremes.

DEVELOPMENT OF FISSILITY IN HETEROGENEOUS ROCKS.

The development of fissility in heterogeneous rock beds is still more complicated. The directions of the forces are exactly the same as with cleavage, but as fissility develops along the shearing planes, in the simplest case this structure forms in two

general directions. In simple folding, as there is differential movement between the layers, the deformation of a portion of a given layer is that of a rectangle (Fig. 8), *abcd*, into a parallelogram (Fig. 9), *efgh*. If the layer were exactly homogeneous and the pressure normal, the secondary structures would be nearly at right angles to each other and at an angle of about 45° to the greatest pressure. According to Becker, in the case of inclined pressure the structures would have different positions, but they still would be planes. These conditions are most nearly approached in the center of a bed which at this place is massive. However, in passing from the center to the weaker, outer part, the original bedding may largely control the direction of parting, the partings occurring near the planes of bedding rather than in those of greatest tangential stress (Fig. 10). The result is that the planes of fissility may change from their diagonal position in the center of the layer, where it is most rigid, to nearly parallel to the bedding on the outer parts, where it is least rigid.

The diagonal *ad* (Fig. 8) is shortened to *eh* (Fig. 9); therefore the fissility along the diagonal *gf* is formed under conditions of compression. This results in producing many approximately parallel planes of fissility. No sooner does a parting form than the laminæ are sheared over one another, thus producing slickensided surfaces. Across this structure along the longer diagonal, in the plane of the shorter diagonal, there is actual stretching of the material. The length of the original diagonal *cb* is increased to *gf*. Parallel cracks are therefore produced in this direction. As a crack once formed easily widens, the result is the production of a few cracks of considerable size. The broken parts do not rub over one another, and hence do not produce slickensided surfaces. These peculiarities frequently lead to oversight of the shearing along the planes of the shorter diagonal. The development of the cracks along the shorter diagonal are strictly analogous of the upward-pointing crevasses of a glacier.

The planes of fissility near the border of the beds, where

the rigidity is less, perhaps originally developed diagonally, may be rotated to a nearly parallel position. This rotation may change the direction of the planes of fissility either in the compressed or the stretched diagonal. The cross fissility will grade into parallel fissility by a gentle curve. On opposite sides of a layer the curves are in opposite directions, just as in the case of

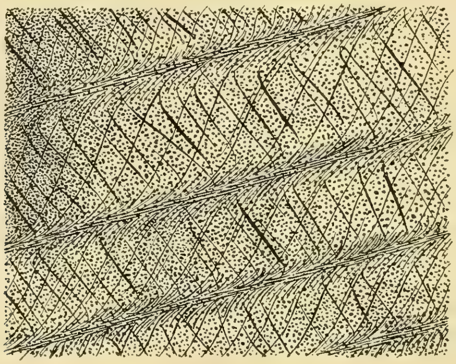

FIG. 10. — Parallel fissility and cross fissility in heterogeneous rock strata.

cleavage, and by these curves it is easy to determine the relative direction of movement of the layers (Fig. 10).

This rotation is explained by Fig. 11, which is supposed to represent a bed of rock made up of thirteen layers differing in rigidity. In passing from the outside of the bed to the center the coefficient of rigidity of each layer is supposed to be twice as great as that of the one next adjacent. The greatest stress is supposed to be the same throughout the bed, and in an inclined direction, and, as shown (pp. 471–472), these conditions may be approximately complied with upon the limbs of folds. When the differential stress exceeds the ultimate strength of the rock, parallel fractures along shearing planes will be formed. The fracturing will continue until the stress falls below the ultimate strength of the rock. The differential stress may still surpass the elastic limit of the rock, or if not, it may again accumulate until the elastic limit is exceeded. Flowage will then begin.

On account of the varying rigidity the two layers adjacent to the center will have a certain amount of differential movement, which may be called 1. The layers next to them toward the outside will have a movement which would be represented by 2; those next to them, 4; those next to them, 8; and the outside layers a movement of 16. Now, connecting similar points in the different layers, a curve is produced which corresponds very

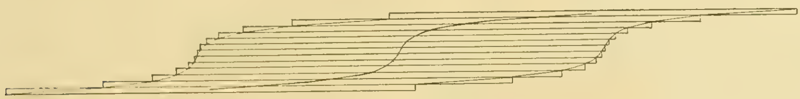

FIG. 11. — Diagram showing rotation of fissility which originally developed in the shearing planes to a position nearly parallel to the bedding.

nearly in form to those which have been observed in nature. The structure produced in the diagonal direction, in the centers of the layers, has been rotated to the position indicated. In different rocks the variation of the coefficient of rigidity would be different from that supposed, and it would undoubtedly vary irregularly instead of regularly. A more accurate discussion would consider each of the layers as indefinitely thin, and the coefficient of rigidity in passing toward the center of the bed as increasing by a minute increment. If different numerical suppositions be made, curves would be produced differing from those represented by the figure, but the same in essential character.[1]

A third way in which the curved fissility above described may be produced is as a structure secondary to cleavage. That cleavage can be produced having the same curves and relations to bedding as just described for fissility has already been shown (pp. 471–474). Such previously developed cleavage would give parallel curved surfaces of weakness. When the rock passed into the zone of fracture fissility would develop along these shearing planes whether they were those of maximum tangential stress or not.

[1] Compare Geology of the Comstock Lode and the Washoe District, by GEO. F. BECKER, Mon. U. S. Geol. Surv., Vol. III, pp. 156–178, 1882.

The above phenomena (probably secondary to cleavage) are finely illustrated in the quartzites of the North Range of Baraboo, Wisconsin and in the massive graywackes of the Ocoee series on the Hiwassee River, Tennessee, combined with cross and parallel secondary structures, as shown by Fig. 10. It is possible that in the cases of both cleavage and fissility as the folding becomes closer and closer the zones of much shearing may extend farther and farther into the rigid beds, producing secondary structures nearly parallel to bedding throughout the limbs of the folds. If the thrust be so powerful as to give the layers isoclinal dips, the secondary structures and bedding will be developed or rotated so as to be nearly parallel throughout the rock-mass, except at the sharp turns on the crests of the anticlines and in the troughs of the synclines, just as in the case of normal plastic flow in homogeneous rocks. (See pp. 464–465).

RELATIONS OF CLEAVAGE AND FISSILITY TO EACH OTHER.

GRADATION BETWEEN CLEAVAGE AND FISSILITY.

In passing downward from the zone of fracture to the zone of flowage, one would naturally expect to find all gradations between fissility in two directions developed in the maximum shearing planes and cleavage in a single direction developed in the normal planes. To this natural expectation the phenomena seem to correspond. Rocks are found having two planes of fissility intersecting nearly at 90° ; others which intersect each other somewhat more acutely, so that the rock breaks up into forms having rhombic or rhomboidal sections ; others in which the rhombs or rhomboids have their axes very long in one direction as compared with those in the other ; and others in which the two directions are so nearly parallel that they are not separated, except by close observation.

According to Becker[1] and Hoskins,[2] somewhat inclined inter-

[1] Finite Homogeneous Strain, Flow, and Rupture of Rocks, by GEORGE F. BECKER, Bull. Geol. Soc. Am., Vol. IV, 1893, p. 50.

[2] Flow and Fracture of Rocks as related to Structure, L. M. HOSKINS, Appendix to Principles of North American pre-Cambrian Geology, by C. R. VAN HISE, Sixteenth Ann. Rept. U. S. Geol. Surv., for 1895–6, pp. 872–874.

secting structures may be explained as original developments, but the former places the direction of greatest pressure in the obtuse angle, while the latter, basing his conclusion on experiments, places it in the acute angle made by the two structures. The phenomena may be partly explained by supposing that after the two diagonal structures developed in the shearing planes, the pressure continuing to be applied with a force between the elastic limit and ultimate strength of the rock, there was a rotation of the two sets into approximate parallelism, just as there is when a net with rectangular meshes is pulled out until the intersecting lines are almost parallel. Professor Hoskins offers another explanation of this transition, as follows (*loc. cit.*): In an early stage of the development there may have been flowage of the rock sufficient to produce a more or less perfect cleavage. The rock, as a result of more rapid deformation or of erosion, may then pass to the zone of fracture. If the stresses remain in the same direction the fractures would not take place along planes of greatest shearing stress, but tend to approach the planes of flattening. In proportion as a previous cleavage was prominent, a secondary intersecting fissility in two directions might very nearly approximate in position with the cleavage. Doubtless in many cases the different causes above given combined to produce acutely intersecting fissility.

FISSILITY SECONDARY TO CLEAVAGE.

For any given layer in a horizontal position in the zone in which fissility is developed, it is probable that horizontal thrust is great in proportion to gravity. If gravity were wholly neglected the greatest shearing stress would be at 45° to the bedding. In the zone in which cleavage is developed it is probable that gravity is very important as compared with tangential thrust. If these are supposed to be equal, the direction of greatest normal pressure would be inclined at 45° to the bedding, and the cleavage planes at right angles to this would also be equally inclined to the bedding, but in an opposite direction. It therefore follows that fissility developing in heterogeneous

rocks in the shearing planes and cleavage developing in rocks of the same character in normal planes may have like directions with reference to the bedding. If cleavage be developed in the normal planes inclined to the bedding, and by denudation this stratum passes to the zone of fracture, as a consequence of the lessening power of gravity, these normal planes are now shearing planes, and fissility is controlled in direction by the previous cleavage structure. It thus becomes evident that it may be exceedingly difficult, if not impossible, to discriminate between original fissility in the shearing planes and a secondary fissility which has been controlled by cleavage. In other cases, as well as these special ones, it is to be expected that a rock in which cleavage has developed under deep-seated conditions would be ruptured before reaching the surface during the long time it is in the zone of fracture. To this expectation the facts correspond. In all regions with which I am acquainted having well-developed cleavage, fissility is also found to a greater or lesser degree. Usually the fissility is more marked here and less marked there, for where a fracture or set of fractures has been formed, there it is easier for further movement to occur. Hence belts of strongly fissile rock are separated by others in which there is but slight fissility. In general, however, fractures along shearing planes occur near together or wide apart within all rock-masses showing cleavage. To this the confusion of the two structures is doubtless largely due. It may be that the use of the term "fissility" should be restricted to a structure developing secondary to cleavage or to bedding, and that original fractures, developing along shearing planes, independent of any previous structure, should be called joints. However this may be, it appears probable that where a rock is broken into very thin laminæ in a uniform direction for a considerable area, the secondary structure originally developed as true cleavage in the normal planes. I therefore conclude that *fissility developing in the shearing planes is usually secondary to cleavage which developed in the normal planes.*

CLEAVAGE AND FISSILITY MAY DEVELOP AT THE SAME DEPTH.

It is clear that in heterogeneous rocks cleavage and fissility may develop in beds of different character at the same depth, for weak beds may be in the zone of flowage at the same depth at which strong beds are in the zone of fracture. For instance, the fine-grained argillaceous beds within a formation may develop cleavage, while the coarser-grained siliceous beds may develop fissility. Thus may be explained some of the cases of change in direction of the secondary structures in passing from one to the other. Also, a bed under a certain weight may be in the zone of fracture if rapidly deformed, and in the zone of flowage if slowly deformed. As has been seen under the subject of deformation (p. 212), the middle zone of combined flowage and fracture is probably 5000 meters thick, and it may be thicker, and throughout this zone either cleavage or fissility may be formed. It is only in the zone of fracture that fissility alone can form, and only in the deep-seated zone of flowage that cleavage alone can form.

C. R. Van Hise.

LARGE-SCALE MAPS AS GEOGRAPHICAL ILLUSTRATIONS.

Verbal descriptions are so insufficient in geographical teaching that supplementary illustrations, in the forms of maps, views, and models, must be employed as far as possible. As an aid towards making a collection of the first class of these illustrative materials, this essay gives an account of a number of examples from a collection of grouped sheets of foreign large-scale topographical maps that have been used in my college course in Physical Geography — Physiography — with much profit during recent years.

The ordinary wall and atlas maps, on a scale of 1–1,000,000 or smaller, show large parts of the world and suggest the general location of one geographical feature with respect to another; they give much general information, but they afford no sufficient indication of topographical form. Land relief is so far generalized on such maps that its conventional representation hardly recalls the image of land forms as we actually see them outdoors. The detailed governmental maps, on the other hand, on a scale of 1–100,000 or larger, show so small an area of country that their location can at first be hardly identified, unless they happen to include some well-known city, or river, or other familiar feature; they must generally be located by means of an ordinary small-scale map which designates their area with respect to known boundaries. But these maps represent so much topographical detail that an examination of them really gives a good idea of the actual minute forms of which the land surface is made up; and they thus supply a basis for geographical observation that is in the highest degree profitable to the student or investigator. They are in effect so many new texts, in graphic instead of in verbal form. Some practice is

necessary in order to interpret their meaning easily and accurately ; but their language is not difficult to learn. Next to a visit to different parts of the world, the study of these maps presents the best opportunity of gaining a real sense of the facts of geographical form with which Physical Geography has so largely to deal. In so far as they enable the student rapidly to generalize the individual facts slowly accumulated and recorded by many observers, they endow him with a power that could not be gained by field work without their aid, except by spending a very long time on the ground.

This value of good maps is evidently not generally recognized or admitted, but it may be claimed and defended. It is as legitimate to base scientific discussions of fact and theory on good maps as it was for Loomis to base his great series of meteorological inductions on the records of our Signal Service. The failure to perceive this is indicated in a recent notice of an essay by C. Abbe, Jr.,[1] in the Monthly Record of the (London) Geographical Journal for March of this year. Mr. Abbe's essay dealt with the features and the explanation of the cuspate capes of our Carolina coast, his statement of fact being based on the Coast Survey charts. The explanation or theory of the origin of the cusps was entirely distinct from his inductions of generalized facts. The reviewer in the monthly notices, however, says: This essay appears to be "a purely theoretical discussion, not based on actual observations." Truly it was not based on *personal* observations, but it was very carefully based on *actual* observations ; and in this respect it was, to compare small things with great, not "purely theoretical," but as truly scientific as Loomis' famous studies.

The habit of using maps, as far as travelers generally possess it, is very largely based on familiarity with atlas maps, as studied in the school room or library ; and it is perhaps for this reason that explorers are so often content to bring home only narrative or locative accounts of their experiences, and so generally satisfied to omit the systematic, rational, explanatory

[1] Proc. Bost. Soc. Nat. Hist., XXVI, 1896, 489–497.

descriptions of the geographical forms that they have seen. The use of large scale maps in teaching may perhaps in part serve to correct this bad habit.

The maps that I shall here refer to are prepared by governmental surveys of European countries. These foreign maps are in general of greater detail and accuracy than those of our country, but of course the latter should not be neglected. They are of great educational value and are in constant use in my teaching, as is more fully indicated below. The use of the foreign maps began with selections from the sheets of the Ordnance Survey of Great Britain and of the Army Staff map of France in our college library. At first the separate sheets were carried to the geographical laboratory and hung in groups on the wall or on racks. But there was much trouble in carrying the sheets back and forth, and in hanging them up in proper order; the white margins of the adjoining sheets prevented their joining nicely, and the constant use of the same sheets, year after year, threatened to injure them more seriously than could be permitted. I have, therefore, in recent years devoted part of the fund allotted for laboratory expenses to the purchase of extra copies of the particular sheets that give the best illustrations, and it is the grouped sheets thus selected that are in part described below. By mounting the sheets in groups on rollers they can be kept on racks in the laboratory, easily hung on the wall when wanted, and quickly stowed away again when done with. The ease of handling thus gained is one of the best means of increasing the use of maps as materials for laboratory instruction in geography. The labor of preparing for an exercise and clearing up the room after it must be reduced to a minimum, especially for those of us not liberally endowed with the spirit of order; otherwise too much time is taken in purely manual work, if indeed the trouble of such work does not lead to its neglect altogether.

The mounted sheets have served so good a purpose that I am now increasing their number as rapidly as possible. They serve not only in the general course in which the principles of

physiography—geomorphology, some of our writers would call it—are treated, but they are invaluable in a later course on Europe, where forms that were before considered chiefly as types of their kind, are considered more fully in their relations to their surroundings, and in the controls that they exert on occupation and movement; but of this later use it is not my purpose to say more at present. The selection of sheets to be purchased for the laboratory is in all cases made from the full set, as far as published for each country, in the map collection of the college library; this collection having been at my intercession largely increased in the past four years. Practically all the European countries are now represented on scales varying from 1–40,000 to 1–100,000. Details concerning the manner of preparation and the form of publication of all the maps may be found in Wheeler's compendious Report on the Third International Geographical Congress and Exhibition at Venice, 1881, published by resolution of Congress as House Ex. Doc. No. 270, second session, Forty-eighth Congress, Washington, 1885. Small index maps, showing the distribution of completed sheets of the modern topographical surveys of the European countries, are very conveniently published in the *Geographisches Jahrbuch* (Gotha) for 1894.

The grouped sheets provide for foreign countries much the same illustrations as are given of our own country by our governmental maps, of which a list of selected single sheets, useful for purposes of study and teaching, was prepared at the suggestion of the Geographical Conference held in Chicago in Christmas week, 1892, and published under the title "Governmental Maps for Use in Schools" (Holt, New York, 1894). There is, however, a marked difference between the home and foreign maps in the much greater detail of the latter. It is true that the maps of our Coast Survey are not excelled for minuteness of detail by any of the foreign maps here referred to; but the Coast Survey charts cover only a narrow border of land along the seashore. The topographical maps of the United States Geological Survey are less detailed; they are truly a great advance

on anything that we before possessed for the greater part of the country that they cover, but they are by no means of final accuracy. Indeed, one of the results that I hope to see from their publication is the education of the public to the need of still better maps and their preparation a few decades in the future. For the present it is perhaps too much to expect that so vast a domain as ours can be surveyed in a manner appropriate to more densely settled European countries, and at a cost that might in many regions approach the market value of the land itself. Information as to this question of relative cost may be found in Wheeler's report, above mentioned, and in the testimony of Major Powell, then director of the United States Geological Survey, before the Joint Commission of Congress on the Governmental Scientific Bureaus in 1884–5 (XLIX Congress, 1st session, Mis. Doc. 82, Washington, 1886).

It is not intended to imply for a moment that better examples of geographical forms are to be found abroad than at home; but that, for the present, better representations of many typical forms can be obtained from foreign than from home surveys. Care should of course be taken to introduce home examples as fully as possible; and for this purpose, a good number of our own maps, grouped and mounted for laboratory study, are in frequent use, and their number is increasing year by year; but there are two lessons that are well taught by the foreign maps. The first is the essential community of individual geographical forms over the world; when well learned in one place, they may be easily recognized in another. The similarity of members of the same family is very striking, and gives good emphasis to the principles of systematic geography. The second lesson concerns the educational value of fine maps; from this I hope in time to see a growth of public sentiment in favor of better maps for our own country, and where should this sentiment be planted better than among college students?

The intelligent appreciation and use of good home maps will be furthered by a knowledge of the kind of information that good foreign maps impart. At present it is seldom that one

notices a traveler, among the thousands who travel, furnished with a map of the district that he is traversing, even though it may be unfamiliar to him. The railroad diagrams, given on time-table "folders," are hardly to be reckoned among maps, as they are nearly always greatly distorted for the sake of bringing the line and the stations of the company that publishes them distinctly before the traveler's eye. Moreover, they omit nearly all indication of physical features; any sign of relief that is introduced is badly drawn. Yet a good map greatly increases the pleasure and diminishes the fatigue of travel to one who is intellectually active enough to take interest in novel surroundings. The name of a river and its course up and down stream, the places that are near but not on the route followed, the further extent of physical features that are partly in sight from the car windows; all these matters deserve recognition at the time of passing them. A student who has had some experience of really good maps will go further than simply supplying himself with the best maps he can now find of his line of travel; he will be so discontent with those that he can ordinarily get in this country that he will contribute towards building up a demand for better maps.

These grouped sheets are simply invaluable in teaching. Students and visiting teachers alike are so ready in their appreciation and praise of them as materials for geographical teaching that I urge the introduction of their use by all who wish to make vivid impressions of the fundamental facts of the science of geography. At a later date the examples here given will be supplemented by briefer accounts of others from Norway, Sweden, Austria, Italy, etc.

The following accounts of a number of grouped sheets are arranged according to countries, rather than according to the features that they represent, as the former plan seems more convenient for the use of teachers and students to whom this paper is addressed. At the beginning of the series for each country is the official name of the survey from which the map sheets

are taken, the scale and general style of the map, the dimensions and cost of single sheets, and the name and addresses of the government agent from whom they may be bought. Many additional details concerning these surveys, their date of beginning and ending, their officers, administration, cost, and so on, may be obtained from Wheeler's report, referred to above. Each group of sheets is given a distinctive local name for easy reference; this being followed by the official numbers of the sheets selected. Orders for copies of these sheets can be sent through any importing bookseller; but it is important to emphasize certain points. The edition on the lightest paper should be selected, when there is any variation in this respect. Particular care should be taken to pick out sheets that match in tint of paper and in depth of impression in printing; otherwise, the several sheets may not match well when mounted together. Blank index maps of each country should be asked for; these are generally furnished free or at nominal cost, and are of value in giving precise location to the group of sheets when mounted. The cost of mounting is often nearly as much as the cost of the maps; but it is essential to have this work well done.[1]

GREAT BRITAIN.

ORDNANCE SURVEY OF SCOTLAND. Scale, one inch to a mile, 1:63,360; "with hills." Sheets, 24 by 18 inches, printed in black, with hill shading in harchures; altitudes of various points given in feet.

NEW ORDNANCE SURVEY OF ENGLAND. Scale, printing, etc., same as the above but sheets of smaller size, 21 by 16 inches. The original ordnance survey has much less expensive hill shading than the new survey, but the new sheets at present cover only a small part of the country.

Sale Agent. Edward Stanford, Charing Cross, London, S. W. Price, per sheet: Scotland, 1s., 9d.; England, 1s.

[1] MESSRS. W. W. WHITE & CO., 66 Pearl street, Boston, have done a good deal of this work for me in a thoroughly satisfactory manner.

THE SCOTCH HIGHLANDS AND THE GREAT GLEN.

Sheets 53, 54, 62, 63, 72, 73, 82, 83.

The Highlands of Scotland are described by Sir Archibald Geikie in his Scenery of Scotland (2d edition) as an ancient mountain region, reduced to a plain of moderate inequality by atmospheric and marine denudation, and then broadly elevated and dissected. Since the dissection, the region has been heavily glaciated and moderately depressed; thus the lochs and the fiords are explained; Professor James Geikie's *Great Ice Age* (3d edition) being the best reference on this part of the subject.

The group of sheet here selected includes the western part of the Grampian Hills (the Highlands next north of the Lowlands), as well as part of the more northern Highlands and of the Great glen by which the northern and southern Highlands are obliquely separated. The chief characteristic of this rugged region is the thorough, mature dissection of the ancient peneplain in which the glens are carved, and the absence of definite trends in the course of the smaller ridges and glens. It seems as if the structure of the uplifted plain of denudation were so massive that the processes of dissection in the present cycle of erosion found few distinct guides to direct their course. The Great glen, which is said to follow an ancient structural line of deformation and weakness, is almost the only example of topographic form that persists in maintaining a definite course for a considerable distance.

Among the special features of this region may be mentioned: Ben Nevis, the highest of the Scotch summits, although only about four miles from the head of Loch Linnhe, a long arm of the sea that enters far into the trough of the Great glen; several straths, or broad valley floors, such as Straths Spey and Spean, the seat of the greater part of the scanty Highland population; the frequent low level and comparatively flat divides on glen or strath floors between opposing streams; several large lakes, such as Lochs Lochy and Ness in the axis of the Great glen, with Quoich and Arkaig on the north and Treig and Etive on the south in subordinate glens, all these and their fellows being ascribed to

glacial excavation by Scotch geologists; diluvial and alluvial valley floors, the first at the head of Loch Carron, consisting of a wash of gravels in front of a local terminal moraine, the second in Glen Glass, traversed by a meandering stream; numerous small rock-basin lakes in corries or cirques at the head of steep-sided glens, and many scattered tarns on the more even upland surfaces; the famous "parallel roads" of Glens Roy and Gloy, just north of Ben Nevis, the relation of the altitude of these beaches to the controlling cols being clearly shown (a list of articles on this interesting locality may be found in *Nature* for May 20, 1880); the peculiar back-handed courses of the streams on the southern side of Strath Spean, strongly suggesting a modification of preglacial divides by glacial erosion and deposition, although not yet locally studied and explained as far as I have been able to learn; the upper part of Loch Linnhe, one of the finest of the sea-lochs, or fiords, by which the western coast is so deeply indented; the twenty-foot sea bench occurs around the shore of this loch, all the villages, roads, and crofts being laid upon it; but it is too delicate for clear representation on these maps.

It should be noted that western Scotland is a good example of a too irregular coast line. The submergence suffered by the western coast has drowned the lower ends of many straths, converting them into fiords, whose waters rise on the steep slopes of the mountain sides; thus the area of easily habitable ground has been unfortunately decreased. A great number of the protected harbors might be to advantage exchanged for low ground on which the harbor-users could live. A highly irregular coast line is not alone an advantage to human development; it must be well proportioned to other advantageous features, as Ratzel has shown (Jahresber. Geogr. Gesell, München, 1894, 83).

THE EASTERN LOWLANDS OF SCOTLAND.

Sheets 23, 24, 31, 32, 39, 40, 47, 48, 55, 56.

The lowlands have been denuded in Tertiary time on a belt of comparatively weak strata (Old Red and Carboniferous, rich in coal and iron,) between the more resistant rocks of the High-

lands on the north and Southern Uplands on the other side. This series of sheets exhibits on the north the border of the eastern Grampians, which repeat the systemless, trendless forms of the Ben Nevis region; the sudden descent to the Lowlands, where the tilted rock structure produces well defined ridges of moderate height—not to be confused however with the numerous drumlins of smooth-flowing form and arrangement and of small elevation. The chief ridges are the Ochils, the Sidlaws, and the Pentland hills; these being resistent interbedded igneous rocks, Carboniferous for the most part, that have withstood the erosion of Tertiary time. The river Tay, emerging from the Grampians on the north, breaches the Sidlaws at Perth, and then turns eastward and follows the axis of the anticline, whose flanks form the Sidlaws on the north and eastern Ochils on the south to its estuary at Dundee. The Forth, breaching the Ochils at Sterling, turns eastward through its estuary or Firth in the broad depression between the Ochils and the Pentland Hills. To the southeast of Edinburgh, the preglacial surface of the Lowland appears to have been less degraded than aggraded by glacial action, for the district is completely fluted with drumlins. The smaller streams hereabouts all follow narrow postglacial channels

The Southern Uplands rise in the Lammermuir group; irregularly dissected, but of much less relief than the Highlands, and generally with smoothly flowing forms.

The most important matter to emphasize in connection with this group is that the moderate altitude of the Lowlands is not due to failure of uplift hereabouts of the ancient lowland of denudation which embraced all Scotland; the district of the Lowlands was uplifted with the Highlands on the north and the Uplands on the south; but while the Highlands and Uplands have, in virtue of their resistant rocks, retained in their skylines good evidence of the altitude to which their entire surface formerly rose, the Lowlands, of relatively weak rocks, have wasted away and as a whole are reduced to an imperfect peneplain of the second generation. It is only where the more resistant volcanic rocks occur among the weaker sedimentaries that a significant

part of the altitude that the whole Lowland district once had is still recognizable. In all this, the Lowlands are much like the broad lowland of the Connecticut valley in Massachusetts and Connecticut, between the uplands of the New England plateau on the east and west ; even to the occurrence over the valley lowland of ridges of volcanic rocks, whose crest lines almost reach the altitude of the enclosing uplands.

It is also important to note that the depression, by which the valleys were drowned into fiords in the Highlands, caused the Lowlands to suffer a general decrease of breadth as well as a penetration by firths. Thus a considerable area of valuable ground was lost, not only for easy agricultural occupation, but also for the industrial pursuits connected with coal and iron industries, here so highly developed.

NORTHERN ENGLAND.

New one-inch maps, "with hills ;" sheets 23–27, 29–34, 38–44, 48–54 ; these sheets had better be mounted in two groups, an eastern and a western.

This series presents a topographical section across northern England. On the west are the revived ancient mountains of the Lake district of Cumberland and Westmoreland, with their radial valleys. Here, as in the Scotch Highlands, structure has little influence on topography ; the ridges are trendless and the dissection about mature. The delta-heads in Derwentwater, Windermere, and other lakes, the delta division of Buttermere and Crummochwater, and of Derwentwater and Bassenthwaite, and the meadows of small obliterated lakes of the Esk, Great Langdale, etc., are all easily recognizable. (See H. R. Mill, Bathymetric Survey of the English Lakes. London Geogr. Journal, V. 1895, 46–73, 135–166.)

The vale of Eden (Trias) separates the highlands of the Lake district from the strong escarpment of the Pennine chain (Carboniferous) on the northeast ; but further south, the two highland areas merge. The vale of Eden is floored with drumlins of large size and excellent form, trending northwest. The

Pennine escarpment of Durham and Yorkshire marks the edge of an eastward monocline of Carboniferous strata, faulted on the western slope, deeply scored by short valleys opening westward and by longer valleys descending eastward. The divide between these two systems of drainage offers an interesting line for study.

The rugged hills of Yorkshire gradually decrease in height and merge into a lowland of Triassic strata, the northern extremity of the long irregular "inner lowland" by which the "oldlands" of Yorkshire, Wales and Cornwall are separated from the double scarped ancient coastal plain of the eastern and southeastern counties. Portions of the infacing scarps of the Yorkshire moors (Oölite) and the Yorkshire wolds (Chalk) are included in the southeastern sheets of this group, exhibiting the systematic arrangement of consequent, subsequent, and obsequent drainage lines that characterizes the whole extent of the ancient coastal plain, from its beginning in Yorkshire southward to the English channel, as discussed in my paper on the Development of Certain English Rivers (London, *Geographical Journal*, V, 1895, 127–146). At their northern termination, the longitudinal features of the ancient coastal plain abnormally turn eastward and are cut across in succession by the shore line, instead of continuing parallel to it, as in the normal arrangement of such forms: Flamborough head and the cliffs of Whitby present sections of the Chalk wolds and the Oölite moors.

Ramsay's Physical Geology and Geography of Great Britain (6th ed.) and Woodward's Geology of England and Wales (2d ed.) are the most accessible sources of information for this district and for England generally, but they give little physiographic detail compared to Geikie's admirable book on Scotland.

The central and southern part of England has not yet been covered by the new Ordnance Survey, and the hill shading of the older Survey is so inexpressive and often so uneven that no other groups for England are at present recommended. When issued, the sheets for the *Weald* (new series, 269–274, 285–290, 301–306, 317–321, 332–334) will be very instructive.

FRANCE.

CARTE DE FRANCE DE L'ETAT MAJOR.—Scale, 1:80,000. Printed in black, with hill-shading in hachures; altitude of various points in meters. Sheets about 19 by 31 inches; may be bought in quarter sections.

Sale agent.—L. Baudoin, Passage Dauphine, 30, Paris. Single sheets, 4 fr.; quarter sheets, 1.20 fr.

THE SEINE IN NORMANDY.

Sheets 19, 20, 30, 31.

This part of Normandy is chiefly a gently undulating upland, dissected by numerous adolescent valleys. Although the Cretaceous (Chalk) and Tertiary strata of the region are, for the most part, nearly horizontal, the upland does not appear to be an initial, undenuded plain, inasmuch as geological studies indicate a considerable denudation as having occurred hereabouts. Whether the upland is a structural plain (a plain formed by the removal of overlying weak strata and the discovery of a more resistant stratum on which further denudation hesitates) or a peneplain of a former cycle of denudation, now elevated and again undergoing dissection, does not appear to be fully determined; but I am inclined to take the latter view, from the peculiar behavior of the river Seine, as well as from the features of the district known as the *Pays de Bray*.

Although the Seine is enclosed in a valley of steep-sloping sides, this beautiful river swings in large curves of notable regularity, exhibiting the *méandres encaissés* of La Noë and Margerie (Les Formes du Terrain, Paris, 1888, 68). It seems to exhibit in these systematic meanderings the habit of maturity or old age, although the steep slopes of the valley sides would not indicate a later stage of development in the present cycle than adolescence. The current explanation of this relation suggests that the habit of meandering was normally acquired by the river during the late stage of a well advanced earlier cycle of denudation, and that the habit was preserved during and after the even uplift by which the present cycle was initiated. In common with

many other examples of this kind, the meander belt (the belt of country included between a pair of lines tangent to the outside of the meander curves) seems to have widened from the measure that it possessed at the close of the former cycle; the evidence of this being found in the more gentle slopes by which the convex lobes of the upland descend into the meanders; while on the opposite side of the river, the descent from the upland to the river's bank is abrupt. The stream has therefore not cut its present valley vertically beneath its former path, but has swung out somewhat to the right and left at its convex turns, encroaching on the plateau on either side, and prolonging the lobes of the upland that descend into the meander curves. A special bit of evidence for this supposition is found at the village of Duclair, some eight miles west of Rouen. Here a small stream, coming from the upland on the north, formerly continued its way through a southward lobe to the next down-stream curve of the Seine; but the ridge that separated the stream from the Seine has now been cut through by the northward encroachment of the meandering river, and for this reason the stream now mouths in the Seine several miles above its former mouth; its abandoned lower valley appearing as a narrow trench running obliquely through a lobe of the upland.[1]

The Pays de Bray is shown in great part on sheets 20 and 31. Structurally, it is a torn anticline, trending and plunging northwest and southeast, with a fault on the northeast side. Now deeply denuded, it determines a series of low ridges and shallow valleys, arranged in the form of a strung bow, with upper Jurassic strata revealed in the space between the bow and the string. The great initial elevation of this anticline is now well beveled down to an altitude on its ridges of a little over two hundred meters, and this accords so well with the general altitude of the Chalk and Tertiary uplands hereabouts, that the ridges of Bray

[1] This accident and certain features of the next two groups of maps are moer fully described in an essay by the author on the Seine, the Meuse, and the Moselle, Nat. Geogr. Mag., June and July, 1896; the same appearing in French in the Annales de Géographie (Paris), V, 1895, 25-49.

confirm the evidence drawn from the meanders of the Seine as to the two-cycle, composite topography of the region. Sheets 11 and 32 include the extremities of this interesting and exceptional deformation. The trend of its anticline carries it northwest towards the Isle of Wight, and suggests its association with the sharp upturn by which the Chalk is revealed on the southern side of that island.

The upland on either side of the Seine exhibits the features of adolescent dissection in the most characteristic form. The digitate valleys, although narrow and steep-sided, have well-graded floors. Much uncut upland still remains between the headwaters of the streams, yet the form and arrangement of the valleys immediately suggests the active headwater extension of every little branch. Some of the roads and railways follow the chief valleys; others traverse the upland, systematically avoiding the valley heads; still others ascend one branch valley, cross the upland and descend another valley. The larger cities are in the chief valleys; but the upland has many villages and is very generally occupied. The steeper valley sides are commonly forested.

The lower course of the Seine is now entered by strong tides, as if the region had suffered a slight depression since the excavation of the valley. The flood tide enters the estuary as a bore or mascaret, best seen at Caudebec, about midway between Havre and Rouen. The tidal scour seems here to have greatly aided the normal action of the river in widening its valley floor. While the convex lobes of the upland that enter the meander curves above Rouen still retain their normal form and allow only a narrow flood plain to the river, those that enter the valley further down-stream are in many cases reduced to acuminate or blunt cusps; the production of these cusps by the gradual consumption of the original lobes being clearly indicated by the transitional forms seen in regular order on passing down the valley, and by the manner in which the cusps point into great concave amphitheaters on the opposite side of the valley. Three examples of this kind about Quillebouef are beautifully shown.

Further down, the valley has been more widened, forming the present estuary; here all traces of the (presumable) primitive lobes and meanders are destroyed. Thus, to a very limited extent, the action of marine currents in excavating valleys, generally accepted as the sole process of origin early in this century, still deserves consideration in the lower valley of the Seine.

The coast of this region gives a remarkably good example of a long continuous sea cliff, of very moderate irregularity, in the production of which the original outline of the land has been completely destroyed. This is the best example of a thoroughly simplified, mature coast line that I have found. The recession of the coast has been so great that the lower trunks of a number of small rivers have been consumed, leaving the upper branches now to enter the sea as independent streams. Rivers of this kind may be said to be "betrunked" by marine erosion; they are easily distinguished from rivers that are betrunked by submergence. The smaller valleys are cut across in mid-height on the cliff face; their deepening not having kept pace with the recession of the cliff, in spite of the strong fall at their lower end. The large proportion of underground drainage through the chalk of the upland has probably much to do with this result.

Villages on the coast are found only where the larger streams have deepened their valleys to sea level. St. Valéry-en-Caux and Fécamp are good examples. Between these valleys, the cliffed coast is absolutely harborless and inaccessible. Jetties are constructed at the valley-mouths to keep the stream-inlets clear; but they are rapidly clogged with the shore drift of chalk flints.

THE CHAMPAGNE.

Sheets 33, 34, 49, 50, 66, 67.

The lowland of the Champagne lies on the Cretaceous formation, enclosed by the Tertiary escarpment of the Ile de France on the west, and descending by a lower escarpment of chalk to the humid Champagne belt on the east.[1] The strata are gently

[1] An excellent account of the physiography of this region is given by de Lapparent. Leçons de Géographie physique, Paris, 1896, 396.

inclined to the west; they form part of the great Mesozoic-Tertiary basin of northern France, whose "oldland" is outlined by the Ardennes on the north, the Vosges on the east, and the Central plateau on the south.

About eighty miles east of Paris, the Marne, one of the chief branches of the Seine, flows across the calcareous lowland of the Champagne, past Châlons and near Rheims, and enters the arenaceous upland of the Ile de France. The valley of the river then abruptly changes from a broad flood plain, lying openly on the rolling low country, to a comparatively narrow trench enclosed by steep slopes from the upland; but as the upland loses height to the west with the dip of the Tertiary sandstones which maintain it, the depth of the trench decreases. About forty miles south of the passage of the Marne, the Aube-Seine traverses the same calcareous lowland and enters the same arenaceous upland. Between the two rivers, and to a certain distance further north and southwest, runs the strong escarpment or *inface* of the Ile de France. Its slope is very largely covered with vineyards, which supply the great wine-cellars of Epernay and Rheims. The prospect from the crest of the inface is a most delightful one. Considering all these features together, it appears that this group of sheets presents a striking example of an ancient coastal plain, whose oldland lay to the eastward, whose strata dip gently westward, and whose existing form exhibits a well-developed longitudinal arrangement of topographical features, in contrast to the transverse arrangement frequently observed. It may be noted by the way that the Brandywine, Prince Frederick, Wicomico and Leonardtown (Maryland) sheets of the United States Geological Survey illustrate the form of an almost maturely dissected coastal plain with transverse features, slightly complicated at present by standing "up to its ankles" in the Atlantic, and thus drowning its valley floors into long narrow arms of the sea. On the other hand, the inner part of the coastal plain of Alabama is an excellent example of a plain having longitudinal features, parallel to its shore line; the Chunnenugga ridge corresponding to the upland

and escarpment of the Ile de France, and the inner black-soil prairies of the cotton belt representing the lowland of the Champagne. The longitudinal arrangement of relief is in these cases entirely due to the occurrence of a more resistant stratum overlying a less resistant stratum. On such a structure, the normal succession of features developed in the mature stage of dissection—especially in the mature stage of one cycle following the old age of a previous cycle—is the *inner lowland*, where the weaker strata are worn down to faint relief; the *inface*, where the retreating margin of the overlying group of harder strata now stands; and the *outlooking slope*, bevelling down the back of these harder strata to the next group of weaker beds, or to the coast. No name is yet suggested for the longitudinal upland that embraces both the steep infacing and the gentle outlooking slopes. The term "ridge" has been used, as in Clark's account of the Cretaceous formations of New Jersey, but ridge is rather too emphatic for so broad and gentle an elevation as the uplands of this kind often present; and, moreover, ridge is a term of general application. What is needed is a term that shall be associated with the upland formed by a resistant stratum of gentle dip as distinctly as inface is coming to be associated with the inland facing escarpment of the upland.

The district between the two master rivers, the Marne and the Seine, is very instructive in exhibiting a number of beheaded and diverted streams, such as are generally characteristic of the inner lowland of coastal plains having longitudinal features. No more perfect and symmetrical example of the kind has come to my notice. It may be explained as follows:

At a much earlier stage of topographical development than the present, and before the weak calcareous belt was excavated to a significantly lower level than the harder arenaceous belt, three other streams ran westward between the Marne and the Aube-Seine. These streams may be called the Surmelin, Petit Morin, and Grand Morin, after the names of their present lower courses. The middle of the three forked into two branches, the Somme and the Vaure, just east of the line between the cal-

careous and arenaceous belts. Since then, all the streams have deepened their valleys. The master rivers have cut down to the greatest depth. The three intermediate streams have cut down to a less depth. From all these deepening valleys subsequent side-streams have grown out, roughly following the strike of the weak calcareous belt; but the most active and important of these belong to the two master rivers. Let us then consider particularly two of these subsequents; one growing southward from the Marne, the other northward from the Aube-Seine. These master subsequents long ago beheaded the Surmelin and the Grand Morin, diverting their upper courses, the Soude and the Maurienne, to the appropriate master rivers, and leaving the upper part of their beheaded lower courses in shallow valleys on the sandy upland. The escarpment has probably retreated two or three miles since these captures, and obsequent[1] streams now drain the area between the inface and the subsequent streams. The rearrangement of drainage, however, has not stopped at this point; each master subsequent stream, continuing its headward growth, has acquired in the most symmetrical manner one of the two forks that once belonged to the Petit Morin; the northern of the forks (the Somme) now flowing northward to the Marne; the southern of the two (the Maurienne) southward to the Aube-Seine; the distance from the elbow of capture to the master river being almost the same in the two cases. Inasmuch as a long time must have elapsed between the early beheading of the Surmelin and the Grand Morin and the later beheading of the Petit Morin, the latter stream had time enough to cut a valley of considerable depth through the upland before it was beheaded. But now, in consequence of its loss of volume by the diversion of its headwater forks, its diminished lower course is embarrassed by the rock waste that creeps down the slopes of its steep-sided valley in the upland, and hence its present head is converted into a marsh—the *marais de St. Gond*—for several miles. Here a local peat deposit has been formed; it is now excavated for fuel, thus giv-

[1] See (London) Geographical Journal, V, 1895, 134.

ing a small economic value to this peculiar stage of river development.

While the considerable length of the two obsequent streams near the elbows of the Soude and Maurienne indicates the lapse of a long time since the Surmelin and the Grand Morin were beheaded, the absence of any perceptible obsequents at the elbows where the forks of the Petit Morin have been captured shows that these last changes have been very recently accomplished; the only perceptible alteration since the capture being a slight trenching of the rearranged stream-lines below and above the elbows. The more active degrading action of the diverted streams and the distinct aggrading action of the beheaded stream are good examples of correlated development. These phases of action are, however, of brief duration.

Taken all together, this is the simplest, most systematic, and most symmetrical example of stream rearrangement that I have yet found. It illustrates to perfection the type of rearrangement that is suffered by streams on denuded coastal plains where an inner longitudinal lowland is enclosed by an upland having a strong inface. This group of sheets is therefore one of the most highly prized in our collection.

THE BAR AND THE AIRE.

Sheets 24, 35.

The Bar is a small stream of very irregular course flowing through a meadow that follows a meandering valley, whose curves have a radius of nearly a mile. The valley bears every mark of having been excavated by a stream that had sufficient volume to flow smoothly around its curves in the fashion followed by the Seine today. The Bar, therefore, appears to be a stream of greatly diminished volume. Ascending its valley southward from its junction with the Meuse, its meandering curves are maintained with almost constant radius, but the volume of the stream progressively diminishes, and at Buzancy the marshy meadow is left without drainage, except such as has been provided by the farmers who have dug ditches between their fields.

Passing still further southward, we come to the Aire, approaching us in a course that leads directly towards the meandering valley of the Bar, but turning sharply to the west near Grand Pré, and in a few miles joining the Aisne, a member of the system of the Seine. The present course of the Aire follows a rather narrow and steep-sided valley that is trenched beneath remnants of a valley plain whose altitude accords closely with the prolongation of the gently ascending meadow-floor of the valley of the Bar. All these things considered, there is every reason to believe that the Aire once followed the valley of the Bar to the Meuse, and that it has been diverted from this path to its present course by the headwater growth of a lateral branch of the Aisne. The probability of this diversion is further proved in two ways: In the first place, the Aire at its junction with the Aisne has a height above sea level of 113 meters; the former mouth of the Aire in the Meuse had an elevation of 153 meters; the former level of the Aire at the point of capture was 182 meters; its present floor at this point is 130 meters. Evidently, therefore, there was good opportunity for the development of a steeper and deeper course by the Aire when the chance came for deserting the system of the Meuse and joining that of the Seine. In the second place, the Fournelle, a small side-branch of the Aisne, now heads close to the Bar, the divide between the two being only six meters above the latter, while the mouth of the Fournelle in the Aisne is 68 meters lower than the Bar. A little further pushing of this divide towards the eastward, and the Bar would be diverted precisely as the Aire has already been.

The meadow that now floors the meandering valley of the Bar has every appearance of having been aggraded; this is a very natural result of the loss of volume in the beheaded stream, which now demands a steeper slope than that which was formerly sufficient.

The head of the Bar is not now immediately adjacent to the elbow where the Aire turns westward, but is eleven kilometers further north; this distance being occupied by a small stream that flows southward to the elbow of capture. The enfeebled

Bar must have been progressively shortened as the south-flowing stream grew headward. While this change must have gone on rapidly for a time following the epoch of capture, its future progress must be extremely slow, because the slopes of the two sides of the divide at the head of the Bar are now not very unsymmetrical.

This set of sheets furnishes the best example of a diminished stream wandering on the aggraded floor of a meandering valley that has come to my notice.

THE COAST OF GASCONY.

Sheets 170, 180, 191, 202, 203, 214, 215.

A great part of the smooth low plain — the Landes — of south-western France exhibits to a nicety the uncarved initial form of an almost infantile coastal plan of Pleiocene strata. Its surface, seldom cut by streams and marshy in many parts, may be traversed for miles without perceptible inequality. Roads, railways, and property lines follow straight courses for long distances. Where streams occur, they occupy very narrow, steep-sided valleys of slight depth, leaving the broad interstream spaces with very imperfect drainage; once the home of the stilted shepherds.

The harborless coast line of this district, from the mouth of the Garonne southward to the Pyrenees, is of remarkable, indeed of exceptional straightness: for miles together, its departure from a direct line is hardly perceptible. Dunes fringe the whole extent of this even coast, and stretch inland over a belt of from two to four miles wide. Their invasion of the plain has been largely arrested by planting pine trees. The dune barrier effectually encloses the water from a number of the streams, which then collects in sub-triangular lagoons, or *étangs*. One of these, the basin of Arcachon, is supplied by the largest stream of the district, and maintains an open channel to the sea; here the quiet *étang* is replaced by a mud plain that is alternately covered and bared with every run of the tides. It possesses the short, blunt water courses, characteristic of tidal scour on a debatable land

surface. It is only where tidal channels of this kind are maintained, breaking across the embankment of dunes, that the shore line shows significant irregularity by bending somewhat seaward.

The surface of the plain is in a very young stage of its life history, but its margin, beaten upon by a stormy sea, must be regarded as more maturely developed. It is just such a flat coast as should have normally been provided with an off-shore bar in the earlier stages of sea attack; but if such a bar ever existed here, it has now been pushed in against and upon the land, the sea bottom deing deepened at the same time, until at present the waves roll in and cut the margin of the plain itself. The prolongation of the slope of the plain does not now coincide with the sea floor; the latter is distinctly below the former (*Reclus*, La France, 103). This satisfactorily illustrates a case of the more rapid advance into the cycle of geographical development under the strong attack of the marginal waves than under the weak action of the superficial drainage; but this is not a constant relation.

The features here illustrated are of a simple kind; but they are of value in preparing the way for a clear understanding of more complicated examples.

GERMANY.

KARTE DES DEUTSCHEN REICHES: Scale, 1–100,000, with hill shading in hachures; sheets 11x13 inches; printed in black, except waters in blue. Altitudes of various points in meters.

Sale Agent: R. Eisenschmidt, Neustädtische Kirchstr. 4/5, Berlin, N. W., Germany. Price of sheets, 1.50 marks.

THE VISTULA AND THE NETZE.

Sheets 223, 224, 225, 226, 251, 252, 253, 254.

The Vistula has a sharp elbow or turn in its course from northwest to about north close to Bromberg, some ninety miles south of its mouth. In prolongation of its upper course, but gradually curving to the westward, is a broad-floored valley now occupied by an insignificant stream, the Netze, which comes

from a side valley on the south about ten miles west of the elbow at Bromberg. This district has been cited by various authors as offering a good example of the diversion of a river from an old to a new course, leaving the old course to be occupied by a stream that is too small for it ; but the cause of the diversion is not clearly stated. It is probably connected in some way with the changes determined by the later phases of glacial action.

On going up the flat valley of the Netze, the plane of its gently ascending floor may be prolonged beyond Bromberg, and discovered again in terraces that now stand somewhat above the present channel of the Vistula. These terraces, like the meadow floor of the Netze, are enclosed by rather well defined slopes that descend from the rolling drift country of the upland. About four miles west of the elbow and close to the town of Bromberg, a small stream, the Brahe, enters the broad-floored valley from a narrow valley on the north. Instead of turning west and joining the Netze, it turns east and, as it were, flows backward to the Vistula, trenching the valley floor slightly on its way. This behavior of the Brahe has very likely resulted from the formation by it of a flat alluvial fan on the broad floor of the Netze trough ; such a fan being the characteristic product of a side stream that enters a broad valley deserted by the master stream. With the growth of the fan across the Netze trough, the Brahe has there formed a flat divide, and, happening to run down the eastern slope of the fan, it found its way to the Vistula instead of maintaining a connection with the Netze, as it must have done for a time after the diversion of the greater river to its new course.

It is important to note that the breadth of the Netze trough is not alone a sufficient reason for arguing that it cannot have been formed by a small stream ; for small streams may, in time, form broad valleys. But if the Netze had formed the broad valley, all the other small streams of the region should also flow in broad valleys, and this is by no means the case. Not only the Brahe from the north and the Netze from the south, but

also the Lobsonka from the north, all occupy comparatively narrow valleys. The Netze, therefore, evidently did not excavate the broad trough that it follows. Furthermore, the sides of this trough are on the whole rather sharply cut, as if by a powerful stream that frequently impinged on one or the other side, and not at all as if the valley had been widened by the slow action of a small stream. A pertinent account of this region may be expected in a promised essay on the ancient rivers of North Germany, by Berendt, in a forthcoming number of the Forschungen zur Deutschen Landes und Volkskunde.

THE ENCLOSED BAYS OF THE BALTIC.

Two groups: sheets 28, 48, 49, 71, 72, 73; and 1, 3, 8, 15, 16, 29, 30.

On the southeastern side of the Baltic there are two bays known as the Frische (Frisian) and the Kurische, for the latter of which we have no ordinary English equivalent. The bays appear to be a product of the moderate submergence which this region has suffered, whereby its marginal lowlands and valleys have been flooded. At present both bays are enclosed by long curving sand-bars, and the original irregularity of the shore line has thus been greatly simplified. These bars are known as *Nehrungen*, a word that does not appear in the usual German dictionary. They are built up to heights of eighty or one hundred, or even one hundred and eighty feet, by great sand dunes whose trend indicates the control by westerly winds. Both of the bars appear to have grown from southwest to northeast, as the end of the bars is now pushed far up towards the northern side of the bays. The curvature of the bars is, on the whole, remarkably smooth, but of greater inequality than that observed on similar bars on our Atlantic or Gulf coast, where the movement of the sea is much stronger than in the Baltic. The outlets of both bays are now protected by jetties in order to prevent their shoaling by drifting sand. The enclosed waters being shallow and quiet, the streams entering the bays form minutely digitate deltas, thus illustrating

their control by stream intention. Similar streams entering a more active sea would be relatively less competent to carry out their intention, and there the deltas would be smooth and simple. The best of these deltas is that of the Nogat, a distributary of the Vistula, which enters the Haff at its southwestern end. An elaborate account of the Kurische Haff has been written by Berendt (Schr. Phys. Oek. Gesell. Königsberg, IX, 1868), and a general account of the Kurische Nehrung may be found in the essay by Bezzenberger in the Forschungen zur Deutschen Landes- und Volkskunde (Vol. III).

THE VALLEY OF THE MIDDLE RHINE.

Sheets 526, 527, 543, 544, 557, 558, 572, 573.

The long depression which the Rhine follows between the Vosges on the west and the Black Forest on the east is explained by German geologists as a *Graben*, produced by the downfall of a long block of country between the uplifted old mountain masses on either side.[1] During the depression of the block, the Rhine does not appear to have been converted into a lake, for borings in the valley floor do not reveal lacustrine sediments, but pass through gravels and sands to a considerable depth. It is therefore concluded that the Rhine aggraded its course and maintained itself as a river during the time of deformation.[2] When this is taken in connection with the next example, it will be seen that the Rhine in this portion of its course must be regarded as a very successful antecedent river, neither being laked where its floor was depressed nor turned aside where its floor was uplifted.

The border of the valley is remarkably well defined north and south of Heidelburg, and for a considerable distance about opposite these points on the west; but only the medial portion of this low ground has the features of a river flood plain. On either side, and particularly on the west, the valley floor slopes

[1] LEPZIUS: Die Oberrheinische Teifebene und ihre Randgebirge, Forsch. z. deut. Landes- u. Volkskunde, I, 1885, 35–91.

[2] PENCK, in Kirchhoff's Länderkunde des Erdtheils Europa, I, 1887, 232, 318.

from the margin towards the center and these slopes are trenched to a slight depth by streams that come out from the mountains; but along the middle belt the earlier and later meanders of the Rhine have developed a broad flood plain of well-defined features. The scars of old meanders are still visible in ox-bow lakes, in curved strips of marsh, and in crescentic depressions slightly beneath the general level of the plain, always convex away from the river, and of radius equivalent to that of existing meanders. These slight inequalities of form suffice to determine the position of many roads and property lines. Through most of this plain the Rhine now flows in a "regulated" channel, much less meandering than its natural path.

The Necker, which now enters the Rhine at Mannheim almost directly opposite its emergence from the mountains at Heidelberg, formerly ran northward along the east side of the plain to Zwingenberg and then obliquely across the plain almost to Mainz before entering the Rhine. The faint scars of its old meanders are traceable for nearly all this distance. These scars are distinguished from those of the Rhine by their small radius of curvature.

THE GORGE OF THE RHINE.

Sheets 458, 459, 483, 484, 505, 506, 525, 526.

The gorge of the Rhine from Bingen to Coblenz, where the Moselle enters from the west, is deeply trenched beneath the uplands of the Schiefergebirge; the Hunsrück on the west and the Taunus on the east. These uplands possess, as a whole, a very moderate inequality; they are in great part occupied and cultivated. Here and there linear ridges of quartzite and other resistant rocks maintain a distinct relief above the general level, forming the Idarwald, Soonwald, Rheingau, etc. Extended views may be obtained from their summits over the surrounding country. One of these points, the Katzenkopf (653 m.), near the village of Rheinbollen, discloses a particularly fine panorama on all sides.

These uplands are among the best examples that I have seen of worn-down mountains, now lifted and slightly dissected, but still retaining over broad areas the form to which they had been reduced while they yet stood close to the former baselevel of the region. The Rhine has cut its gorge directly across the uplands, and when this is taken in connection with its behavior on the open valley further south, it indicates very clearly the existence of the Rhine as a river antecedent to the differential movements by which the broad outlines of the present geography were determined.

That the Rhine actually flowed across the country that is now raised to an upland position is demonstrated by a more minute study of the form of its present valley; this study being made, however, much more easily on the ground than by means of the maps. A broad trough is sunk to a depth of about a hundred meters beneath the general level of the upland. On the floor of this trough is a level deposit of loess lying upon water-worn shingle, which in turn rests upon the bedrock. The present gorge of the Rhine is a narrow trench that is incised about 250 meters beneath the loess-covered floor of the trough. The path of the Rhine in its gorge is much less sinuous than that of the Moselle on the west and the Lahn on the east. It is possible that this difference of behavior may be explained as the result transverse course of the larger river, and of the longitudinal courses of its side branches. During the former cycle of denudation the longitudinal streams would generally have had wider valleys and better chances to meander on their floors than the transverse Rhine could have had; and the result of their former meandering on flat valley floors is now seen in the meandering path of their steep-sided gorges.

Following the lead of the larger rivers, the smaller side streams are actively at work dissecting the upland; but as yet they have seldom made much progress in their work. It is noticeable that upon the uplands of the Hunsrück three streams now flow south or southeast through the residual ridges of the Soonwald on their way to the Nahe and the Rhine, thus suggest-

ing an inheritance of their headwaters from geographic conditions long since vanished. Note should also be made of the antecedent course of the Nahe through the spur of the upland just back of Bingen.

THE GORGE OF THE MOSELLE.

Sheets 502, 503, 504, 522, 523, 524, 539, 540, 541.

The Moselle from Trier to Coblenz follows a deep and, for the most part, narrow and steep-sided valley, by which the upland of the Hunsrück is separated from that of the Eifel. Through the greater part of its course, the valley has a very strongly meandering habit, thus repeating the behavior of the lower Seine. In this case, however, there is fuller demonstration of the inheritance of the existing incised meanders from the normal meanders of the river when it was flowing on a broad-floored valley in an earlier cycle of denudation. The upland through which the Moselle flows is composed of greatly disturbed rocks which form part of the ancient Hercynian mountain system, stretching from the Ardennes northeast into Germany. Nearly all traces of mountain form was, however, lost in the long cycle of denudation in which the even uplands were produced; occasional ridges, like the Hochwald and Soonwald, alone remaining. At the close of that cycle the Moselle must have earned the right to meander as freely as it choose. The present meanders, it can hardly be doubted, are inherited from those early ones. The inheritance, however, is that of a third generation; for here, as in the case of the Rhine, the trench of the Moselle is sunk beneath a flat-floored trough, which, in turn, is excavated below the general level of the uplands. The existing meanders must therefore be regarded as following those that were developed upon the floor of the trough, while the trough meanders followed those that had been still earlier developed on the upland when it was a lowland. In the neighborhood of Berncastel, the necks of some of the spurs that enter the meanders have been reduced to a very narrow measure; in one case, the railroad that generally follows the river banks shortens its course by tunnelling through

the neck of the spur. Just above Berncastel, the narrowing of the necks of the ancient spurs has been carried still further, and two of them are cut through by the river; the abandoned meanders being now distinctly traceable in flat meadows that curve around the isolated extremities of the spurs. Sheets 503, 504 include several of the *maare* in the volcanic district of the Eifel.

These and other grouped sheets have been so instructive and profitable, both in studying and teaching, that I urge their use upon students and teachers of physiography in normal schools and colleges. They furnish numerous examples of well defined physiographic features, and thus serve to extend the fund of geographical types and illustrations far beyond the narrow limits within which the subject is usually carried forward from early school years. On some future occasion I hope to present briefer notes on a larger series of grouped sheets, to give further indication of the richness and variety of easily accessible material of this kind.

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EDITORIAL.

THE "Report of the Research Committee, appointed to Collect Evidence as to Glacial Action in Australasia" (Brisbane, 1895), and the Presidential Address of Professor T. W. E. David before the Australasian Association for the Advancement of Science (of like date) together with Professor David's recent paper before the Geological Society of London, on "Glacial Action in Australasia in Permo-Carboniferous Time," bring forth into fresh and collective form a large mass of data respecting ancient glaciation which merit the most serious consideration of students of the climatic phases of the earth's history. In some degree, to be sure, the facts are familiar to geologists, but the magnitude of the phenomena have not been so clearly and impressively set forth before. It is shown by detailed sections and by specific data of clear import that the Permian glacial phenomena of Australia, have great vertical as well as lateral extent. At Bacchus Marsh, for instance, there are at least eight successive deposits of well characterized glacial till, reaching an aggregate thickness of over 1100 feet. The whole section, including interstratified conglomerates, sandstones and shales, reaches 2000 feet. Six of the glacial bowlder beds reach thicknesses ranging from 132 to 235 feet. From this it appears that the vertical thickness greatly exceeds that of the Pleistocene glacial deposits of like situations. The known localities range through 12° in longitude and 21° in latitude and reach north of the tropic of Capricorn. The number of discovered localities has already become large. Extensive striated pavements occur at different places. The scratched bowlders are abundant and often large, reaching in one case a mass of thirty tons. In New South Wales a group of coal beds comprising from twenty to forty feet of coal occurs in the midst of the series.

These determinations do not rest upon the testimony of any single geologist or even a few geologists; they are the joint product of no less than twenty observers. In the light of these impressive phenomena, taken in connection with the extensive glaciation demonstrated in like manner in India and the less known phenomena of southern Africa, it is no longer our privilege to ignore or slight these most remarkable glaciations in our attempts to explain the origin of glacial periods. The agency assigned, it would appear, must be competent to explain very extensive, very prolonged and very much interrupted glaciation, at seemingly low levels, in areas that lap across the tropics on both the north and south sides of the equator. Before any hypothesis is entitled to popular propagation (except under due qualifications) it should frankly meet and fully satisfy these limital and most extraordinary phenomena.

T. C. C.

Reviews.

Expedicion Cientifica al Popocatapetl. JOSE G. AGUILERA Y EZEQUIEL ORDOÑEZ. Mexico, 1895. 8vo, 48 pp., 6 plates and 2 charts. Published by the Geological Commission of Mexico.

THE volcano, to a description of which this pamphlet is devoted, is perhaps the most widely known of any in the Western Hemisphere. From the time of Cortez to the present, its towering height and condition of semi-activity have made it a subject of continual interest. Yet the descriptions of it so far published have, from a scientific point of view, been meager and fragmentary. Humboldt in his work on Mexico makes but brief mention of it. Later travelers, notably Felix and Lenk, have added much to our knowledge of the mountain, but their accounts have failed to give sufficient data to permit intelligent comparison of its characters with those of other great volcanoes.

It is, therefore, a real service to the science of geology which the authors of this pamphlet have done, in preparing so comprehensive and careful a description of the features of Popocatapetl. While full recognition is made of the work of previous observers, the larger part of the data are original with the authors themselves. So comprehensive, moreover, is the treatment of the subject that future study of the volcano may profitably be confined to special portions or phases of its structure.

The work begins with a description of the orographic relations of the volcano, it being shown that it forms the most southern and highest part of the Sierra which separates the valley of Mexico from the valley of Puebla. The form of the volcano is stated to be that of an elliptical cone whose major axis has a northwest-southeast direction. The cone is formed of three parts, the upper, covered by a mantle of perpetual snow, and hence having a uniform slope, the median, composed of sands whose surface is cut by radiating channels made by the flow of waters from above, and the lower, which is part of the highly

irregular and tortuous fold of the Sierra. Several great barrancas or ravines made by the flow of waters from above cut the lower portion of the cone and modify somewhat its relief. They take their origin in semicircular depressions of the cone which have a more or less crateriform aspect. The most notable of these is that at the head of the Barranca del Fraile. It cuts a great amphitheater-like section out of the northwest flank of the mountain and is surmounted by a peak known as the Pico del Fraile.

This great depression has usually been regarded as an old crater, but in the view of the authors it is simply a cavity cut in the mountain by atmospheric and stream erosion. Their reason for this view is that the slope of the strata of lava is everywhere uniform with that of the major cone. Had the lava exuded from this point they argue, the slope of the layers would have been away from the crater on all sides.

The form of the crater at the summit of the mountain is that of an elliptical cylinder resting upon an inverted cone.

Its greatest depth is 1640 feet (505 meters), greatest diameter 1988 feet (612 meters) and least diameter 1299 feet (400 meters). These determinations, especially that of the depth, differ considerably from those made by previous observers. The form of the crater, the authors state, was probably originally that of an inverted cone. Their explanation of its present form is that by the accumulation of material dislodged from its walls, the interior has been filled up and the outer border extended till the interior walls are now nearly vertical.

In regard to its structure, Popocatapetl is classed with the volcanoes known as stratified, on account of the resemblance to sedimentary formations presented by the succession of currents of lava of which it is made up.

In the character of the lava of these successive outflows, a marked gradation can be traced, corresponding to a gradual decrease in the heat and energy of the volcano. The lavas of the lower currents are granular, devitrified and of trachytic structure; those of the upper currents, vitreous, of resinous luster and amorphous structure with a few phenocrysts. The difference in structure is ascribed to the fact that the upper currents being farther from the source of heat were more nearly cooled when poured out and became solid before time sufficed for crystallization.

A difference in mineralogical composition between the upper and

lower lavas is also noticeable; the lower lavas are basalts containing a large amount of olivine; the upper, hypersthene andesites.

Considering the products of the volcano as a whole, the life of the volcano can be divided into three periods, indicating a gradual decrease in its heat and energy. These may be denominated the period of lava eruptions, the period of breccia eruptions and the period of eruptions of ashes.

Between the successive outflows of the first period, varying intervals of time intervened. During the intervals the surface of the outflow became covered with masses of cooled and broken lava which were cemented by the next outflow into a breccia. These layers of breccia are prominent through the lavas and serve to mark the boundaries of each outflow.

During the second period of the life of the volcano, solid material was ejected in the form of bombs, blocks of lava and pumice. These were more or less assorted by running water and consolidated by argillaceous and ferruginous cements. Their character and relative position may now readily be studied in the Barranca of Tlamacas.

During the last period of the life of the volcano, the coarse, black sands or ashes which cover the surface of the upper part of the cone were extruded. These have been moved about by winds and waters till now they are deposited over the surface of the cone in masses of very unequal thickness. Between these deposits are intercalated thin lenses of alluvium, indicating periods of repose in this phase of the volcanic activity as well.

Attention is called to the similarity of the material poured forth by the volcano to that produced by eruptions in the valley of Mexico, and on this fact is based a suggestion as to the age of the lavas. In the latter place, the first eruptions of hypersthene andesites are covered by sediments in which are found remains of *equus*, *cariacus*, *elephas*, etc., showing that the eruptions must have taken place in the early Pliocene.

The early eruptions of Popocatapetl which produced olivine basalts are believed to have been contemporaneous with these, inasmuch as they underlie andesitic lavas similar to those of the Santa Catarina volcano. The lavas of the latter mountain are known to have been ejected at the time when the Pliocene sediments were forming over the valley of Mexico, hence the andesite lavas of Popocatapetl may be regarded as late Pliocene in age.

Attention is called to the fact that in this same region, volcanoes within very short distances of one another were producing at the same time, the one basalts, the other andesites. The practical contemporaneity of the outflows is proved by the fact that beneath the lavas of each have been found human skulls and evidences of human industry.

The occurrence is paralleled in modern times by the outflows of Jorullo and Colima. The lavas of the former are basalts, of the latter, andesites.

The last pages of the work are devoted to a succinct description of the three types of rocks which go to make up the volume. They are classified as labradorite basalts, hypersthene andesites, either with or without augite, and trachytes.

The height of the volcano is given as 17,701 feet (5450 meters).

Observations made by the present writer during a recent visit to the volcano, in general go to substantiate the views presented in the work under discussion. He can, however, hardly agree with the authors in regarding the formation of all the vertical surfaces of the mountain as the result of erosion.

It is especially difficult to understand how the walls of the crater could have become vertical in this way. The degradation of cliffs to form slopes is a phenomenon of common occurrence, but that the reverse can take place seems exceedingly doubtful.

The vertical walls of the crater seem to the writer rather to give evidence of the character of the force which produced the latest eruptions. It was an upward force, bringing up from below broken lavas and ashes. As the force was sufficient to send these many miles away from the volcano, it is not unreasonable to suppose that it was sufficient to break through and remove the lavas in the crater. Thus would be left a conduit with vertical walls, the only effect of subsequent erosion upon which would be that of degradation. That this is the process going on at the present time, a short stay in the crater makes evident.

It seems much more probable that the walls of the so-called old crater may have been formed, as the authors suggest, by a process of erosion, yet their statement of the mode of formation is hardly satisfactory.

Another feature of the volcano which the authors explain as the result of erosion, seems to the writer to have had a different origin. This is the assemblage of lavas at the point called La Cruz. Here the lava lies in great ridges which jut out prominently from the slope of

ashes which cover the cone. Since these lavas are similar to those found in the crater, the authors regard them as vestiges of the latest flow, from which the areas connecting them with those above have been removed by erosion. The lineal character of the ridges, however, and their prominence, seem to the writer sufficient evidence for regarding them, as is usually done, lateral outbursts through the side of the cone.

The work is illustrated by several fair plates giving sketches of portions of the volcano. The employment of photographs for purposes of illustration would have been, however, more satisfactory.

OLIVER C. FARRINGTON.

RECENT WORK ON THE CARBONIFEROUS OF KANSAS.

Stratigraphy of the Kansas Coal Measures, by ERASMUS HAWORTH, Kansas Univ. Quart., Vol. III, pp. 281–295, 1895.

Classification of the Upper Palæozoic Rocks of Central Kansas, by CHAS. S. PROSSER. Journal Geology, Vol. III, pp. 682–705 and 764–800, 1895.

Permian System of Kansas, by F. W. CRAGIN. Colorado College Studies, Vol. VI, pp: 1–48, 1896.

A generation ago the upper Carboniferous succession in Kansas was the subject of prolonged and ofttimes somewhat acrimonious discussion. Since the close of that memorable debate there has been until very recently very little investigation undertaken in the state. So, for more than a quarter of a century practically nothing has been done to clear up the doubt concerning the question of the natural subdivisions of the Carboniferous system of that region ; and for the same period little attempt has been made to decipher the stratigraphy of the formations which constitute the whole eastern third of the state.

Of late, within a few months of one another, three important memoirs have appeared which have greatly extended our knowledge of the stratigraphy of the region. These contributions, primarily to Kansas geology, are by Dr. Erasmus Haworth, Professor Charles S. Prosser, and Professor F. W. Cragin. The work along the three lines being undertaken without regard to one another the results are in no way directly connected. While this method of treatment has the

advantage of giving conclusions which have been reached independently it lacks the greater completeness which would have existed had the work been compared and adjusted in advance to publication. Through the details given the advancement of the whole subject is such as will enable a rational classification of the strata to be outlined with little fear that any radical departure will be necessary in the future. The results are not only important as regards the state of Kansas but they are especially valuable in pointing out more accurately than ever before the stratigraphical relations between the Carboniferous rocks of that state and those of Missouri and Iowa. The Kansas work supplies the information heretofore lacking which enables the geological history of the whole Western Interior coal province to be made out with a reasonable degree of satisfaction. The most important point of all however is that the three papers furnish the facts which until now have been needed to outline a rational classification of the Carboniferous deposits of the Mississippi basin. The main subdivisions are so clearly defined over the whole Western Interior regions that it becomes a matter of surprise and even wonderment that so many other and diverse lines of demarkation should have been selected. The systematic arrangement of the main subdivisions of the Carboniferous is now practically the same in Iowa, Missouri, Nebraska, Kansas, Arkansas, Indian Territory and Oklahoma ; and hence forward these states can have a uniform nomenclature so far as the upper Palæozoic formations are concerned. The minor stages of each of the major subdivisions or series differ in different localities. They will probably have to be established separately in each of the several states. Local members have already been named for the greater part of Kansas and the number and limits of similar local formations have not been entirely neglected in other parts of the province.

As the outcome of the recent work, and other late investigations of which special mention need not be made at this time, the Carboniferous of the Continental Interior appears to be separable into four principal sections or series. In a general way these correspond essentially with the four old subdivisons : the Lower Carboniferous, Lower Coal Measures, Upper Coal Measures, and the Permian. While the old and new lines of separation have approximately similar positions they do not coincide. Moreover the old lines were vague, different in the different states and even in different parts of the same state. The new lines are sharply defined in all particulars. In the field they are

easily distinguished by their lithological characters and the features which they impart to the physiography. Stratigraphically and faunally they are equally well marked.

Between the lowest of the four series, the Mississippian limestone, and the lower or productive Coal Measures, composed chiefly of argillaceous shale and sandstone, the separation is everywhere distinct. Limiting the shales above and forming the base of a series of more open sea deposits, known as the upper Coal Measures, is the Bethany limestone, of which the Erie or Triple limestone of Kansas and the Winterset limestone of Iowa are equivalents. In the field the thick limestone forms a more or less well-defined eastward facing escarpment from north-central Iowa through Missouri and Kansas to Indian Territory. The uppermost member of the upper Coal Measures is also a limestone with characteristic features. It has been traced from southeastern Nebraska across Kansas into Oklahoma. These three lines separate with remarkable clearness the great body of strata of the western Mississippi basin, which lie between the Devonian and the Cretaceous. A wealth of information is now at hand by which the four series can be fully described in accordance with modern rules of nomenclature: the geographic distribution, the stratigraphic position, the lithological character and the biological definition of each is capable of exact consideration.

Of the three articles, that by Dr. Haworth treats of the second and third great subdivisions, that of Professor Prosser the third and fourth, and that of Professor Cragin chiefly the fourth or uppermost.

Professor Haworth's paper is a summary of a fuller account of the stratigraphy of the Kansas Coal Measures that is to appear soon. The formation of the lower Coal Measures to which local names are given, are, beginning at the base, the Cherokee shales, Oswego and Pawnee limestones and the Pleasanton shales. The total thickness is regarded as 800 feet. In the upper Coal Measures are: the Erie or Triple limestone, Thayer shales, Iola limestone, Lane shales, Garnett limestone and Lawrence shales. Above the latter are the Oread, Lecompton, Topeka and other limestones up to the Cottonwood limestone. These are separated by beds of shales of greater or less thickness which, with two exceptions, are not named. The aggregate thickness of the upper Coal Measures is placed at 1950 feet.

The formations of the lower Coal Measures and of the lower half of the upper Coal Measures appear to be well defined. The exact deter

mination of the formations of the upper half of the upper Coal Measures has been reserved for subsequent consideration. The summit of the upper Coal Measures is placed some distance above the top of the Cottonwood limestone. "The divisions between the Permian and the Coal Measures has not been located definitely and will probably be placed not more than 100 feet above the Cottonwood Falls limestone, as the palæontologic evidence upon which such a division must depend seems to show that the greatest change of marine invertebrate life occurs not long after the formation of the existing fossiliferous shales lying above the Cottonwood Falls rock."

Paragraphs are given on the ratio of the limestone to shale and sandstone, on the characteristics of the limestones and sandstones, on the inclination of the strata, on the origin of the shales and on the general conditions of deposition. Two subordinate papers are attached which are in reality parts of the one under consideration. The first is on the division of the Kansas Coal Measures and the other on the coal fields of Kansas, in which are described the stratigraphical locations of the various coal beds in the different formations. There is also a consideration of the physical and chemical properties and the commercial values of the coals.

Although no special review of Professor Prosser's contribution is here necessary, as it appeared in the JOURNAL OF GEOLOGY, it should be mentioned for the sake of completeness. The most important feature perhaps, is the determination of the line of separation between what has been heretofore called the Upper Coal Measures and the Permian, the horizon selected being the fossil-bearing shales lying immediately over the Cottonwood limestone. The various subordinate formations are very clearly defined and fully described.

In Professor Cragins' account of the Permian system of Kansas a number of new names are proposed. Although Professor Prosser's work is noted and some quotations made it is not clear just what the relations are of the subdivisions proposed by the two authors. The following is the scheme suggested:

Cimarron Series.
- Kiger division.
  - Big Basin sandstone.
  - Hackberry shales.
  - Day Creek dolomite.
  - Red Bluff sandstones.
  - Dog Creek shales.

Salt Fork division.
- Cave Creek gypsums.
- Flower-pot shales.
- Cedar Hills sandstones.
- Salt Plain measures.
- Harper sandstones.

Big Blue Series.

Summer division.
- Wellington shales.
- Geuda Salt measures.

Flint Hills division.
- Chase limestones.
- Neosha shales.

A statement of particular significance and interest is that "In the past four decades geologists have repeatedly shown that the passage from the Carboniferous to the Permian system in Kansas is gradual and includes an interval of so-called Permo-Carboniferous rocks which combine the faunæ of both systems. The evidence of continuity and the question of the proper disposal of these intermediate rocks have led to much difference of opinion, some even having gone to the extreme of abandoning the Permian as a system of age, merging it in the Carboniferous, in attempting to avoid the difficulty of the situation. The Permian in America, is, however, a great and widely distributed system, difficult of diagnosis, though it may often be, from paucity of palæontological data. It is finely developed in Texas, where it has great thickness and has been found to have occasional fossiliferous horizons to within less than 300 feet of its summit. The Permian of the Kansas-Oklahoma basin undoubtedly has many similarities to that of Texas, but it is probably on only one or two of the terranes of the upper Permian, especially in the medicine lodge gypsum, that stratigraphic continuity or even parallelism of physico-geographic conditions can be traced between them. It therefore seems necessary to treat the Permian north and south of the Ouachita mountain system as belonging to two distinct basins, and profitless to attempt divisional correlation between them."

CHARLES R. KEYES.

Wissenschaftliche Ergebnisse der Finnischen Expeditionen nach der Halbinsel Kola, pp. 857 and numerous plates and maps, Helsingfors, 1890–92.

The expeditions referred to in the title were sent out by the Finnish Society of Botany and Zoölogy, the University of Helsingfors and some

private parties in 1887–89–92. The object was the study of the fauna and flora, geology, geography, and meteorology of the Kola peninsula or Russian Lapland which lies between the White Sea and the Arctic Ocean. It is roughly 200 by 300 miles in area and was practically an unknown territory, the largest on the map of Europe. Moreover, the region presents some peculiarly interesting features. It is a moderately high and smooth area almost entirely within the Arctic circle. It was almost directly in the path of the Scandinavian ice-sheet as it advanced into Russia. It also promised to throw some light on the transition from the Scandinavian "Urgebirge" into the sedimentary formations of North Russia or from the Alpine regions of the west to the flat Tundras of the East. The scientists of the party were Dr. R. Enwald and Professor J. A. Palmen, zoölogists, Drs. V. F. Brotherus and A. O. Kihlman, botanists, Dr. W. Ramsay, geologist and Mag. A. Petrelius, geodesist. The results were many and various. The peninsula was found to be a plateau of moderate height with a mountain mass, West of the center reaching a height of 3900 feet. The main part of the area shows only crystalline rocks, granite, gneiss and schists called by Ramsay "Grundgebirge." There are little fringes of sedimentary rocks on the north, south, and southeast coast. These are without fossils and are referred to the Devonian. The mountains referred to are thought to be eruptive and are composed of nepheline-syenite. This highland furnishes a favorable place for the study of glaciation. Proof was found that the highest land was covered by an eastward moving ice-sheet. Following this was a so-called "Nunatak" period when the ice moved southeastward. There were abundant proofs of local glaciation reaching well toward the present. A considerable series of rock was collected and the results of petrographical studies by Dr. Hackman are given in much detail.

The biologic work was none the less important. Maps are given showing the tree limit and the distribution of pines, birches and junipers. The flora was found not to be so strongly Arctic as had been supposed. The mosses and lichens were studied by Brotherus and Sanio, while Kihlman treats of the natural conditions of the country as regards the growth and distribution of vegetation. We know no equally full and lucid treatment of the subject for an Arctic region. We wish in closing to express our appreciation of this work as a whole. The University of Helsingfors, the Finnish Society and the

scientists of the expedition are to be congratulated both on the wisdom which planned and carried out the enterprise and on the rich fruits which attended it. We will await other publications of this university with pleasant anticipation. D. P. N.

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